# THE JOURNAL OF Industrial Engineering


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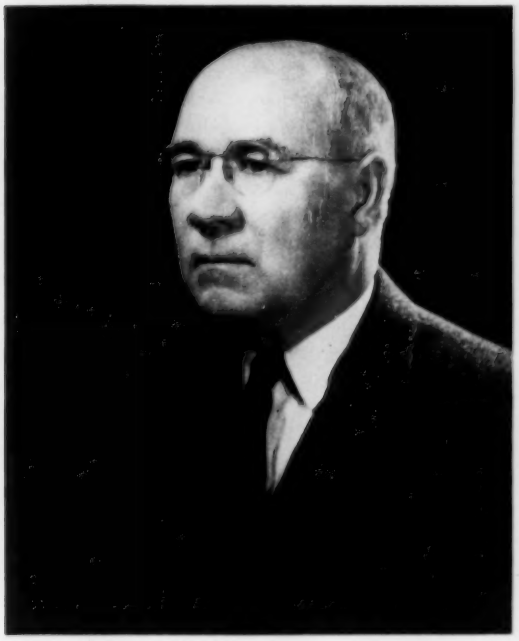
# PRESIDENT'S MESSAGE



## Industry's Stake in the Teacher Shortage

By Howard P. Emerson

*President, American Institute of Industrial Engineers, Inc.*

Industrial engineers increased 376% from 1940 to 1950 (12,000 to 46,700) according to the U. S. Census of Population.

The growth in demand for industrial engineers is continuing at a rate faster than the colleges can fill it with qualified graduates. Twelve hundred graduated in Industrial Engineering and closely related engineering curricula in 1955. This rate is still not enough. Local chapters of AIIE can help by getting more students interested in Industrial Engineering as a career. But more students in turn will require more faculty. Demand for engineering teachers is expected to double in the next fifteen years.* The problem of finding teachers is equal in importance to, or even more important than, that of expanding student enrollments in engineering.

One conclusion of the members of the Industrial Engineering Division at the ASEE meeting at Ames, Iowa, in June of this year was for the colleges to seek greater cooperation on this problem from industry. AIIE might be the go-between.

Here is the problem the colleges would put up to industry. To turn out the stream of qualified engineering graduates which industry needs, requires 3% fed back to keep the stream flowing. Without the application of this feed back principle the system won't operate, and industry won't be able to get the trained men it needs.

*"Future Engineering Enrollments and the Problems They Pose" paper presented by Ross J. Martin, University of Illinois, at the annual meeting of the American Society for Engineering Education (ASEE), June 28, 1956, Ames, Iowa.

### Flow Diagram for Production of Engineers

The figures used are not exact, but are intended to show approximate relationships.

The accompanying diagram illustrates the problem. To get 25,000 graduate engineers per year (surveys actually report a need for 40,000) will require an input to the system of 43,000 freshmen. Such a loss of 40% in a production process would not be tolerated by industry. Reduction in this ratio is a responsibility of the colleges and of the secondary schools which furnish the raw material. The whole teaching system is thus involved in the problem.

The diagram shows a reservoir of students in close proximity to a smaller reservoir of teachers, with a semi-permeable membrane providing action and interaction in an educational process not too well understood. Four years of exposure is the standard time of contact before the product is matured and ready to flow out to industry.

The feed-back principle involves drawing off from this production line, or back from industry, enough personnel to keep the teacher reservoir filled. Each year industry attracts about 800 from this reservoir but 400 come back, leaving a net loss of 400. Another 400 leave the system, through death or retirement. The colleges seek industry's help in replacing this net loss of 800 teachers per year, equivalent to 3% of the number of engineering graduates, leaving 97% for industry.

### How Industry Can Help

There are a number of ways in which industry can help with this problem:

1. Release qualified employees to study for masters degrees while helping to teach. One or two years taken off from industry will bring a graduate up to date in his field and give the college a part or full time instructor. Industry will gain since teaching experience is useful in some jobs and the new knowledge can be applied.

Some of those who have come back to teaching from industry testify that one develops faster personally and professionally in the teaching field and that one gets a perspective of the whole field which would not be obtained as quickly in industry. An increased, more flexible interchange of personnel back and forth from industry to teaching would help the teacher shortage.

2. Industry can help provide consulting and summer work to give added income to teachers. Industry needs to train its own staff in Industrial Engineering since it can't get enough I.E. graduates. Why not hire I.E. teachers to do this each summer?

Such opportunities for outside income from consulting, research and teaching help make it possible to find good men for teaching at the present time.

3. Industry might finance chairs or professorships in I.E. subjects with enough money to get outstanding men from industry to fill such positions.

4. Industry might provide men on leave to teach for one quarter, semester, or year. Contacts with a live wire faculty would be mutually beneficial. Industry already provides qualified men for night extension teaching. Some of these might be induced to go into full time teaching jobs.

5. The real answer is more money for teaching salaries. The cost of adding one or two thousand dollars to every engineering teacher's salary would not be more than the cost of one submarine, or two jet bombers. The engineering teacher trains those who design our fighting equipment.

6. Industry gets the products of engineering colleges below cost. All other materials and energy it uses are priced at cost plus. Why should state legislatives or loyal alumni subsidize the production of the graduates which prosperous industry seeks?

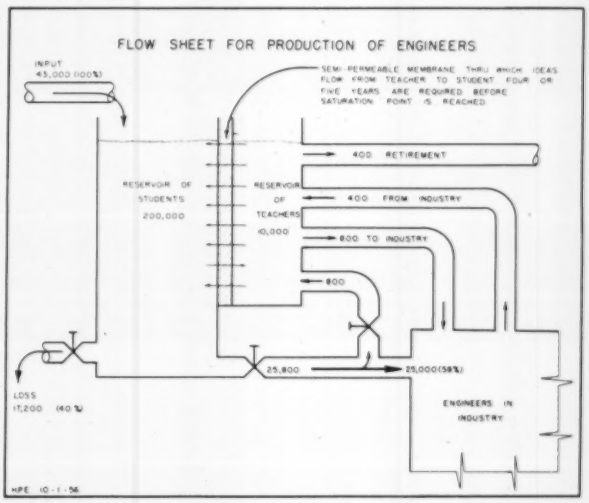
Shouldn't industry pay more for this valuable commodity so that teachers salaries can be raised? Present beginning salaries which industry pays students just out of college are based on competition for a commodity in short supply, and do not help the producers of the commodity. The colleges, competing for the same men for instructors, offer $1000 per year less, not counting supplemental outside income.

When industry finds a short supply of other required materials, it attempts to help relieve the shortage to prevent unprofitable bidding for goods in short supply.

7. Those who are good teachers might consider teaching for a few years after retiring from industry. One man recently went back to school for a masters degree before doing this. Why not retire early with this in mind?

8. New departments of industrial engineering are seeking accreditation from the Engineers' Council for Professional Development (ECPD). Others are being developed, at least on paper. The bottle neck is staff, qualified teachers with engineering degrees and industrial experience.

Thirty-two accredited curricula plus 15 options in accredited curricula now constitute the source of graduates both for industry and for teaching. Local AIIE chapters can help by encouraging local colleges to add I.E. departments and seek ECPD accreditation.




## Conclusion

AIIE can act as a go-between in helping the colleges and industry solve the teacher shortage.

Local chapters through placement services can help uncover good teachers. The Columbus chapter of AIIE provides a job clearing house, including that of finding teachers for University I.E. departments seeking teaching personnel. The Education Committee of AIIE stands ready to work with local chapters, industries, or individual members interested in helping with this problem.


## TEACHING POSITION AVAILABLE

Visiting lecturer of Associate Professor level needed on January 2, 1957. Must be graduate of accredited Industrial Engineering curriculum and have had 5-10 years industrial and teaching experience. Will be required to teach Statistical Quality Control, Factory Planning, Engineering Economics, etc. Opportunities available to teach night courses and to conduct private consulting practice. Good opportunity for advancement.

Write to:

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# The New Industrial Engineering*

By D. G. Malcolm

*Director of Operations Research, Booz, Allen & Hamilton*

A look at the new industrial engineering is certainly an exciting and pertinent subject to explore, for we are in an era when technological change seems to be coming at an ever-increasing rate. In harmony with this change and aiding it are the electronic data processing means available and the mathematical techniques undergoing research. And we must consider the shifting social values in our society as evidenced by trends in labor relations over the past decade. All of the factors are causing serious shifts in, or additions to, the approach required of the industrial engineer.

I shall attempt to confine this discussion to a characterization of the industrial engineering which is emerging in this climate mentioned above. Speculation concerning the utility and application of specific techniques and the precise organizational form this new industrial engineering may take will be left largely to the reader.

In order to make this characterization, it will be necessary to develop a frame of reference for the discussion. We shall do this in due course by means of a definition of Industrial Engineering and a discussion of a diagram depicting what may be called "The Industrial Engineering Process". However, let us first take a look at where the profession is now and what some of the trends are which are creating the need for this new industrial engineering.

The growth of the profession from 1940 to 1950 as evidenced by U. S. Census figures[1] was truly phenomenal. During this period the overall engineering profession experienced a growth of 51% in individuals reporting some branch of engineering as their occupation speciality. During this same period the individuals listing industrial engineering increased 7½ this rate or a lusty 376%—the total number being 46,700.

There are undoubtedly several reasons why these figures should be suspect. The problem of categorizing, for census purposes, a lot of individuals who became specialists in management problems during the war probably forced considerable non-engineering individuals into this category. This has had a lot to do with the breadth of the functions ascribed to the profession and the general vagueness in its definition. Many of these individuals undoubtedly would not be considered professional industrial engineers today. It is interesting to note, however, that even if we discount the census figures by 50%, the growth was still in excess of chemical engineering, the next leading engineering branch in growth during the period.

This growth has been rather uncoordinated, generally neglected and undirected philosophically by the academic engineering groups in our universities and lacking a professional society which could spell out the engineering objectives of the profession and also the problem areas wherein development could and should be concentrated. As a result of such factors operating, or rather *not* operating, we find that the definition of industrial engineering will vary considerably depending upon with whom one talks.

Engineering has been defined as the "art and science by which the properties of matter and sources of power in nature are made useful to man in structures, machines, and manufactured products."[2]

It has been characteristic of the engineering profession in America to develop along the lines of problems currently needing solution in our economy and society. Thus it was quite natural that when problems of organization and management in industry required systematic study by what is referred to as the "engineering approach", the resulting subject material developed should be grouped in this rather nebulous area referred to as "industrial" engineering. The development during the war years was not characterized by the development of analytic tools, but rather by the development of descriptive techniques that literally caused the problems to disappear by shedding the light of systematic fact upon the problems under study. The techniques developed were and *are* adequate for these purposes.

However, during this same period, other engineering disciplines had undergone a fundamental shift from emphasis on the "practical" and experimental approaches—*the art of engineering*—to the greater use of mathematical methods of analysis refined through cooperative work with applied scientists, mathematicians, and other engineering disciplines—*the science of engineering*—as an era

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* Adapted from an address delivered at the AIIE Symposium on Industrial Engineering, Cornell University, 21 October 1955.

[1] U. S. Census Bureau Letter—Series P44, No. 1, February, 1944 and Census preliminary data published by Engineering Manpower Commission March, 1953.

[2] Webster (unabridged).

began. Thus the present day engineering function is characterized by the development and use of a considerable "research" function which develops new analytic approaches and probes into the basic structure of our physical world.

The same sort of approach is beginning to pervade the industrial engineering profession, offering the opportunity to develop in an accelerated manner along similar analytic and research lines. We can now attempt to make an "engineering" definition of the profession.

I should like to mention a few factors that are accelerating this gravitation toward the "new" industrial engineering.

### Automation

The general trend toward a higher proportion of indirect labor is being accentuated with the advent of the automated production line. This is causing a shift in where the greatest dollar economies can be found in a plant, but *more* important, it is raising a whole series of new problems. This is perhaps best brought out by a statement made by Dwillar J. Davis of Ford Motor Company at a recent congressional subcommittee meeting.[3] In essence, Davis related that for every 2 workers displaced by "automation" slightly more than one additional skilled maintenance technician was required to support the new machines. It should be pointed out that all others so displaced were absorbed and that the total number of workers remained constant. Thus, automation brings with it a trend towards "monitors" or observers rather than operators, and we have some estimate of its impact quantitatively.

The conventional techniques of time and motion study are no longer nearly as important nor as applicable in measuring the work and contribution of such individuals. Now, the emphasis in getting efficiency of the operation depends more upon the attitude, the attentiveness and the reaction of the employee. This is opening up entirely new problems in obtaining that attentiveness, etc. The approach to this problem will require new methods of stimulating and measuring the effectiveness of such employees.

In regard to other indirect labor, it is well known that this has been on the increase. More elaborate management control systems, requirements for greater governmental and management information, etc., have caused an increase in the number of such activities which are essentially data-processing activities. Electronic Data Processing will be useful in these areas.

### Support Staff

Corollary to the above is the growth of support staffs. Many of our large aircraft companies as well as electronics manufacturers are in effect becoming engineering design companies with very large staffs engaged in analytic work which support the designer. In one large company the trend in the past 10 years has been for this support staff to increase 10 to 15 fold, causing a further decrease in the proportion of direct labor.

The individuals comprising such a staff may be thought of as applied scientists or engineering scientists. We're just beginning to see the problems this creates. The type of person in this activity is motivated by entirely different drives and values. These have to be considered in the design of the work situation. The problem of work measurement and prediction of performance of developmental tasks is of major concern in such companies, for this is the part of the company that produces the right product design at the right time. Conventional techniques obviously are not adequate and cooperation with research in psychology and sociology is necessary to effectively create the most effective work situation and to estimate the performance of the individuals. These new techniques are emerging.

### Emphasis on Development

With developmental work becoming the order of the day, the production part of the business is faced with introduction of changes in the product to be made, and also the methods of production at a generally increasing rate. Thus, the economics of introducing change itself are becoming a subject of greater interest and are of considerable strategic importance in company planning.

### Data Processing

Most of our industrial engineering systems such as production, inventory, and cost control systems, require the storing, analyzing, and comparing of large masses of data. Thus many of our control systems in essence are data processing systems. The limitation of the human mind, and the increasing need to search rapidly for record of the many events that have transpired, or are scheduled to transpire, represents a distinct time consuming situation.

Now, with the advent of the digital and analog computers, and with the advent of newer mathematical techniques and theories, it becomes increasingly clear that we are cracking the barrier of some of our problems of data storage which will in turn permit the redesign of our systems of control. However, parenthetically, this will not be done without considerable work, research, intelligence and education on the part of the industrial engineer, and is squarely the big challenge that faces the industrial engineer in the job of creating and implementing the "new industrial engineering". Integration and simplification of data systems is possible and is being performed.

At this time it seems desirable to present the definition that was referred to earlier and to indicate the problem of making definitions that have meaning to all individuals. There are many reasons why we might be interested in making a definition. One reason would be to explain what industrial engineers do, or to provide a basis for evaluating whether someone is or is not an industrial engineer.

[3] Subcommittee of the Joint Committee on The Economic Report, 14 October 1955.

Another reason might be to describe the objectives of the professional field in order to provide a framework for the orderly growth of the profession and to permit a forecast of problem areas. Other purposes might be to describe the norm of what industrial engineering is now and to attempt to define the best organizational function it should take in a given company.

These are all important and necessary reasons. However, it is the purpose here to arrive at an "engineering" definition of the field, one that will permit the orderly growth of a body of design knowledge in the functions normally considered our responsibility. In that vein I would like to offer a definition, mindful of the fact that such a definition will always be changing since the definition of engineering itself is a changing factor, and that the semantics of today probably will not be sufficient for tomorrow.

Industrial Engineering is that branch of engineering concerned with the *continuing analysis* of the *dynamic relationships* between men, material, machines, methods, and information; the *synthesis* of these elements into the *design* of *organizations*, the *work situation*, and various types of *controlling systems* for the purpose of enabling the *achievement* of some desired, ethical *objective* (generally at the *least cost* of company money and *worker effort* expended, and providing the maximum satisfaction of all parties involved). The industrial engineer is charged with the *responsibility* for the *installation* and the *successful performance* of these human systems and for providing adequate *predictions* of their *performance* and cost.[1]

This particular definition probably is going to give one a little trouble. Perhaps a depiction of the industrial engineering process will be helpful. See Figure 1. The same words that have been used in the definition are now used in block form to show the "process of industrial engineering," as it may be termed. Box #1 marked "Analysis" indicates that the job of analysis is to consider the various combinations of relations between men, machines, materials, methods, and information either in respect to time or with regard to distance, environment, satisfaction or the energy involved, *or* in respect to *all* of these values. This is done by one of many, sometimes alternate, analytical techniques in order to get the facts of the relationship and to provide a basis for the synthesis of the facts, or elements, into a design for an organization or controlling system, or the work situation.

Then, the industrial engineer should be able to predict the cost and the performance of these designs under varying conditions, and to give some statement of the

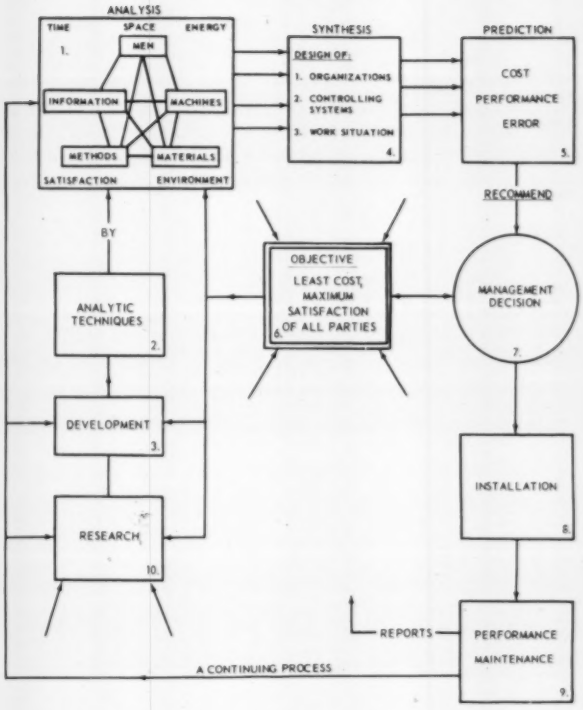


FIG. 1. A Depiction of the Industrial Engineering "Process"

probable error of his prediction. Then, upon comparison of these alternate suggestions, if there be any, a recommendation is made to management for their review and either acceptance or a suggestion of modification or a new analysis.

In any event, at some time, there will be forthcoming an improved design, at which time the industrial engineer's responsibility is to make an installation of this design. The installation is of course a time consuming job and, as evidenced by much of the literature of industrial engineering, there is a continual job of what might be termed "fire-fighting," in order to make sure that the installation sticks and is satisfactory. Finally, block #9 indicates that the industrial engineer is responsible for the performance and maintenance of this system (not its operation however), and may be responsible for periodic reports of all types that may be used by management.

A loop back has been drawn to indicate that all of this should be a continuing process. That is, these particular systems or methods, should be looked into continuously from the point of view that experience gained in performance, experience gained from research into the newer techniques of analysis, and that development of and extension of these may provide different system synthesis. Some of the problem areas caused by the trends discussed earlier (automation, emphasis on development, etc.) can be best indicated by a look at this return loop and reflecting

[1] Subsequent to this presentation members of the symposia developed the following definition which has been officially endorsed by AIIE:

Industrial Engineering is concerned with the design, improvement, and installation of integrated systems of men, materials and equipment. It draws upon specialized knowledge and skill in the mathematical, physical and social sciences together with the principles and methods of engineering analysis and design to specify, predict, and evaluate the results to be obtained from such systems.

that the industrial engineer has often lost sight of the fact that he is dealing with a continuing or dynamic process. He quite often arrives at a design of a system, installs it and then cuts out this return loop of making a re-analysis of the basic design or particular synthesis. Too often, he merely monitors the methods and produces the reports. In many cases Industrial Engineering operates almost entirely within box #9 and often without real consideration of boxes 2, 3, 4, 6, and 10.

**Analytic Techniques**

A second problem area concerns the analytic techniques that are used, and more importantly, the research activities that produce these new techniques about which we are hearing. It should be mentioned that the functions marked Development and Research refer particularly to the R and D supporting Industrial Engineering methodology and not the R and D on the product of the company. Some of this, of course, may come from areas *outside* the industrial engineering function. This aspect of the profession will be discussed in greater detail later.

In regard to box #2, some of the problems and developments that are occurring in relation to industrial engineering methods of analysis should be discussed. The various techniques of analysis that have been used by industrial engineers are listed very roughly in the order of their development and application.

*Methods of Analysis*

Process Charts
Motion Study
Flow Diagrams
Surveys
Work Measurement
Fatigue Studies
Cost Analysis
Engineering Economy Studies
Mathematical Methods
Statistical Analysis
Programming
Stochastic Processes
Servo Theory
Communication Information Theory
System Simulation
Factor Analysis

Toward the bottom of the list will be noted a whole host of new techniques, or analytical methods if you please, that are looming up over the horizon.

How do these fit into the new industrial engineering?

First, it is important to recognize that such techniques are being developed by other than industrial engineers as well as by industrial engineers. Some of the techniques are merely in the research stage and are requiring considerable development in the way of specified procedures by the industrial engineer in order for successful applications to be made.

Secondly, the distinguishing characteristics of these new methods of analysis are: (refer to Box 1)

1. Some of the newer techniques permit inclusion of more variables in the analysis that may be important in the design. Many of our present techniques will consider only two variables, e.g., men and machines with respect to time (the process chart) or with respect to space (the flow diagram). It is characteristic that most of the present techniques are static, and consider at the most only two or three of the factors at a time.

2. More of the variables may be considered simultaneously and in a dynamic method that permits a better insight to their interaction. Many of the techniques are essentially competitive and are often alternate tools for solving the same problem.

3. As a result of making analogs of the real system—either mathematical models, or computer models—*evaluation* of different designs for control systems can be made. Thus, we can now look forward to a *theory* of inventory control—a *theory* of production control and the like.

The impact of this will be considerable, but not as revolutionary as some would have us believe. While many of present industrial engineering techniques are essentially descriptive, and the overall effect of the industrial engineering approach is sometimes experimental, the good judgement and experience of the business system *has been* sufficient and adequate to come up with decisions that are probably quite satisfactory and probably will continue to be. However, many of the questions concerning, say, inventory control, regarding when are the best times to reorder, what is the optimum relation between inventory size and production efficiency (minimum balance), what review periods should be used, etc., have been answered by *experience* rather than by *analysis*.

Competing techniques of System Simulation and Servo theory are offering the possibility of analyzing such systems in a dynamic context and should permit analytic determination of many policies and procedures, and should thereby provide the basis for the development of optimum sets of rules.

The technique of System Simulation (sometimes called the Monte Carlo method) and stochastic processes are permitting analysis of interference problems, balancing and peaking problems. Where we have formerly considered only the average time, it is becoming possible to allow (in the analysis) for the statistical nature of many of the elements in a production line.

**Synthesis and Design—The University's Role**

The results of our analysis, whatever type it may be, lead us to a process of synthesis, box 4. Here we design Organizations, Controlling Systems and the Work Situation which may be further described as follows:

*Synthesis into Design for:*

1. *Organization*
   Structure
   Procedures
   Policies
   Measures of Effectiveness
2. *Control Systems*
   Production Control
   Inventory Control
   Quality Control

Cost and Budgetary Control
Labor
Support Staffs
Organization
3. *Work Situation*
Plant Layout
Work Methods
Wage Determinations
Material Handling
Maintenance

At present it appears that in many industrial engineering departments in business we are breaking away from only considering what may be called the microscopic aspects of the work situation. There has been a tendency, perhaps, in the I. E. academic research adjunct, to over-concentrate in the detailed analysis of the work methods. While these are necessary lines of investigation, this has resulted in a lack of attention to the synthesis of the individual jobs into the whole work pattern. In other words, there has not been nearly enough attention paid to the more powerful analytic tools for system analysis.

However, at this time, a survey of our universities indicates a real drive and effort to move in this latter direction. Courses in linear programming, probability theory, information theory, servo mechanisms, operations research etc., are appearing at an increasing rate. In my opinion, as greater experience is gained by faculty members, there will be a shifting of emphasis in the appropriate undergraduate technical courses for the industrial engineer. Many of our colleges now have the goal of training engineers to be in a position to *introduce* change in about 15 years—*not* merely to be able to keep up with it. Fifteen years is chosen because this represents approximately the time before the engineer is able to make the most effective contribution to his company.

Thus, industrial engineering managers should begin to have a wider range of training from which to select new employees, and are already finding it necessary to modify their organizational structure in order to most effectively use these talents. It may well turn out that graduate engineers from other engineering branches, research groups, etc., will be more satisfactory employees for the industrial engineering department before this educational process is fully established.

To summarize, it is evolving that the greatest payoff in the coming decade will probably come from increased attention in this systems area. A theory of organization seems to depend first upon satisfactory solution to the problems of control. We can look forward to Communication Information Theory to be very useful in getting at the problem of optimum communication flow and as one enthusiastic writer[5] indicates:

"The particular strength of the communication theory lies in its ability to describe in the precise language of mathematics the statistical performance of all components, human or mechanical, of the industrial engineers' realm," and "With further experimental data and proper adjustment for fatigue etc., his (Paul Fitts)[6] Binary Index of Task Performance could well become the key to true time and motion synthesis."

In other words both the microscopic and macroscopic areas may be analyzed.

## Prediction of Cost Performance and Probable Error

Turning to another subject—the methods for prediction of cost, performance and probable errors in these estimates, are requiring more attention. In order that the right decisions will be made and installations of new systems may be effected in the least time, more frequent, elaborate and accurate predictions will be required. This will require consideration of the likely trends in labor relations, the increasing number of technological choices available, the likely need for increased frequency of change in basic processes and methods and an increased knowledge of what a competitor is doing in *his* process. The techniques of Time Series Analysis and Time Reduction Curves will receive increasing attention.

## Management Decision and the Objectives of the Enterprise

And don't forget that management is entering the picture in more than one way as evidenced by boxes 6 and 7 in Figure 1. Management is continually looking at this *heart* of the system—box 6. What are the overall objectives and policies that will permit the most satisfactory growth or profit of the entire enterprise? Management has the job of fitting together many other functions, of which industrial engineering is only one, into a best overall solution.

While this "heart" is being worked on from many factors from the outside, we can say that modern management is quite aware of the need for expression of human values included in systems design and at the same time is mindful of the need to produce the best possible product at the least cost of money and worker effort. As a result of this philosophy, management is asking questions of the methods of analysis that are beginning to put greater emphasis on Research and Development of techniques for better, more timely and comprehensive analysis.

The new industrial engineering function that is emerging is being characterized by gearing management's thinking to box 10 instead of putting the emphasis and heat on box 1. More and more industrial engineering functions are building-in this research function. This will permit understanding and application of the newer methods of analysis at an earlier date and should have the return of permitting

[5] *The Industrial Engineering Application of Communication-Information Theory*, A. B. Rosenstein, The Journal of Industrial Engineering, September-October, 1955, Volume VI, No. 5.

[6] *Current Trends in Information Theory*, Pittsburgh, University of Pittsburgh Press 1953.

a broadening of the objectives of the entire enterprise. This in turn is a competitive tool in today's manpower shortage.

### Installation Theory

The industrial engineer is generally responsible for the installation of his designs. The length of this installation phase and the frequency of introducing change are subjects of increasing importance.

It is desirable in general to install a system, etc., with the minimum of confusion, so that the learning effect (Time Reduction Curves in the Aircraft Industry) is minimized. Also, with a general desire on management's part to be able to introduce new models, or products, at an increasing frequency, it becomes necessary to select the analytic technique (where different tools are available) that minimizes the total cost of the production.

So it should be evident that there are gains, by way of reduced cost and competitive advantage, to the enterprise that is able to most successfully cope with this "installation phase." It therefore becomes quite important for more systematic knowledge to be brought to bear on how long it takes for a control system, an organization etc., to respond to the new desired way of doing things. To reduce the installation time requires a feed back to R and D and should be the subject of considerable exploration by the industrial engineer.

With everyone else coming up with a "theory of this" or a "theory of that", perhaps this offers the Industrial Engineer a chance to coin a theory also. Perhaps this area of study of the installation schedule and procedure should be referred to as "Installation Theory" with its objective "study of the most overall efficient way of introducing a change."

### Performance—Maintenance

In many companies the responsibility for performance of others in regard to a given design is the ultimate responsibility of the industrial engineer. If they or the system can't do what he says is possible, it becomes the industrial engineer's job to determine the source of the trouble. If it is his design, he has a redesign job to do. If it is faulty line management, supervision, or interpretation, the industrial engineer must insist on correct procedure.

There is a trend in the industrial engineering function to get out of the data processing area. Thus, reports issued by Industrial Engineering Departments become more of the nature of interpretive reports of other organizational functions whose systems the I. E. function is responsible for designing. The I. E. departments conceived as a sort of Consulting function may well become an organizational precept and indeed is the central theme of the "New Industrial Engineering."

### Summary

I have attempted to describe what appears to me to be the new industrial engineering—being mindful that there are many who will believe that this concept is too narrow—that industrial engineers work in other problem areas which might well have been included.

In any event, I hope I have left the thought that the future of the industrial engineering profession is in the hands of those who would be called industrial engineers. It can either continue its growth towards becoming a bonafide engineering discipline, or it can fail to meet the challenge and its practitioners become the installers, administrators of another design function.

The significant indications are that this challenge *is* being met, that an orderly progressive growth is being made in both industry and in the academic institutions. The process can be catalyzed only by understanding the process and augmenting the problem areas which have been delineated.


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# Production Programming

By R. E. McGarrah

*Associate Professor, Department of Industrial and Engineering Administration, Cornell University*

In planning for the broad, aggregate production output for future periods, management is frequently forced to decide intuitively the program for meeting fluctuating sales demands. There are essentially three choices: 1. Employees must be hired or laid off, or must work overtime or "undertime"; 2. Inventories (or order backlogs) must be increased or decreased; 3. There must be a combination of changes in work force and inventory levels. The costs associated with each choice are intangible, difficult to evaluate, but nevertheless very real. In Part I this paper describes these costs and includes a suggested list of the incremental costs of changing production output levels, and costs of excessively high or low inventories. In Part II a model of a linear program for minimizing these costs is described.

## Introduction

There is a certain logical objective of production programs for successive time periods in which the sum of the costs of changing the production output rate and the costs of excessive inventories (or order backlogs) is a minimum. With sales demand fluctuating, it should be possible to program a relatively stable rate of production volume by planning inventory levels to absorb the interim fluctuations in sales demand. Such interim variations are often of high frequency and low amplitude. In the analogy of the servo mechanism, the inventory acts as a "low pass filter" which dampens the effects of sales variations (1). This concept is not new. Management has used intuitive judgement in programming production output for years, but too often without knowing how costly or how profitable such decisions have been. Nowadays, however, the pressures of the guaranteed annual wage or guaranteed employment, the accelerated increase in the fixed capital investment per employee, and the more rapid obsolescence of inventories—all these factors—indicate the need for a more rational method of making these decisions. In other words the consequences of erratic production programming decisions are becoming more critical to the life of the business. Any rational method must first require an estimate of the pertinent costs of production programming decisions.

To clarify the frame of reference of this discussion, this paper is concerned with total *aggregate* production output rate per future time period, and the total *aggregate* finished goods inventory level at the beginning and end of the time period. It is assumed that the structure of the manufacturing and marketing functions is practically fixed (i.e. no drastic changes in plant and equipment arrangements, nor in the warehousing and distribution system have occurred, or will occur). The time period may be a month or a season, depending upon the characteristics of sales fluctuations, the sales forecasting and factory ordering procedures, and the manufacturing time cycle, etc.—i.e. those factors determining the frequency of establishing a "master" production schedule. This master schedule determines the frame of reference within which detailed manufacturing schedules of customer orders, specific manufacturing activities, etc. are determined. Obviously there is significant interaction between the tactical decisions of detailed schedules and the strategic decisions of master schedules, and this will be discussed in a later section of the paper.

## PART I

### Incremental Costs of Changing Production Programs

The costs of concern are only those which are incurred with a change in the production output rate and with the deviation from optimal inventory levels. These costs are *not* the same as accounting costs of products, or of total materials, labor and other direct production expenses, which must be borne during the period of *any* production program. Product costs are only indirectly involved in the determination of inventory costs, to be described later. The incremental costs of changing programming decisions are intangible, difficult to measure, *but very real*. Good judgement in the assignment of values to these costs will assure "at least an approximate recognition of the policy and resources limits they represent" (2).

Obviously the total manufacturing costs will increase as a result of a decision *to change* the rate of production output. But we are interested *only* in that part of the total costs which is increased *because of the decision to change the present rate of output*, i.e. the direct costs of programming decisions. If a firm continues to produce at the same aggregate output rate, no costs are incurred because there has been no change. These costs may be classed in two groups. First are those expenses incurred *once* during the period of the new program (at the beginning), such as hiring or layoff costs. Second are the expenses which *may* be incurred for the duration of the period of the program, such as overtime, shift premiums, or standby expenses of idle facilities. The incurrence of the second group will depend

upon the particular programming decision. For example, some (but not all) decisions to increase output will result in increased direct labor costs because of shift or overtime premiums. Likewise some (but not all) programming decisions may effect a change in direct material costs because of changes in vendor price discounts on quantities purchased. In other words, the total incremental costs of changing production programs consist of "oneshot" expenses of carrying out the immediate adjustment in output rate, plus the additional direct expenses of production incurred during the period of the program.

It is believed that three critical factors determine the total incremental costs of changing production programs:

(a) The production output rate and inventory level of the current program about to end, i.e. the *point of departure*.
(b) The *magnitude of the change* in output level and/or inventory level.
(c) The length of the period of the production program.

The influence of the *current* production rate is fairly obvious. If the firm has been operating at 80 per cent of normal capacity (single shift operation), an increase of output could be effected without additional costs of overtime premiums or second shift premiums. A decrease in output might involve laying off key personnel who are difficult to replace. However if the plant has been operating at 100 per cent of normal capacity for single shift operation, an increase would very likely involve overtime costs, or second shift premiums, and extra supervision. A decrease in production could be effected by reducing the work week, or by laying off the personnel having lowest seniority and skill, and these costs would not be as great as the layoff when the plant was at 80 per cent of normal capacity.

The effect of the magnitude of the change in the current output level or inventory level is also obvious. Hiring or laying off 50 employees is more costly than when only 5 employees are involved. Similarly a large boost in the inventory level may involve acquiring additional warehouse space, and a large reduction of inventory may involve abandoning of some warehouse space. The magnitude of any maximum change in the output rates of sequential programs is likely to be restricted because the supply of skilled labor in the local labor market may be limited. Also the union contract may indirectly restrict the rate at which employees can be laid off, because of complicated seniority clauses.

The length of the programming period will affect the costs of changing production programs. The costs of a decision to increase output involving sustained overtime operation will obviously require summing the overtime premium expenses over the period of the new program. Overtime premium costs would be greater for a six months period than for a six weeks period. The choice of the programming period will depend upon the cost of forecasting, the errors in the forecasts, the time to consolidate and study new market information to improve the forecasts previously made, and the cost of making changes in the detailed manufacturing schedules already released to the shops, as mentioned in (7). This choice is an important, difficult decision, for it involves facing squarely the problem of logical classification of "strategic" and "tactical" factors of business programming. More study is needed on this problem.

The three proposed determinants of the cost of changing programs are not mutually exclusive. More new employees can become effective in six months than in a period of six weeks. And if the current program has been at 80 per cent of normal capacity, new employees would be expected to boost production to 100 per cent of capacity more readily than if the current program had been at 100 per cent, and output was to be boosted to 120 per cent. Hence, the period of the program, the magnitude of the change in output, and the "point of departure" are all interrelated.

### Incremental Costs of Changing Aggregate Production Output Rate

The costs of increasing production rate are not likely to be the same as the costs of a decrease in production output rate. Therefore the incremental costs are listed separately. A criterion for judging what costs are to be included in this list is the extent to which these costs could be avoided by a more stabilized production program over several periods. Following are some suggested incremental costs of changing the level of production output:

1. Costs of increasing production output rate:

a. Employment and training.
   (1) Interview and selection. The number of applicants interviewed is apt to exceed the number selected. The time spent by the interviewer (s), including the direct clerical overhead expense of the employment office should be included.
   (2) Investigation of references, security check. Time and clerical expense of investigating character references; processing photographs for security badges, employment office escorts, including employment office direct overhead expenses.
   (3) Physical examinations. The number of prospective employees examined, the physicians' retainer fee per examination, direct overhead expense of the clinic, medical and clerical supplies, etc., should be included.
   (4) Payroll entry preparation. Computation of various standard payroll deductions (taxes, social security, group insurance, union dues, etc.) requires additional time by payroll clerks, additional office supplies, etc. The hourly clerical salary and the payroll office direct overhead rate per hour should be included in this estimate.
   (5) Training new employees. This would include the average time required to train a new employee, including the hourly costs of the foreman's or experienced worker's "*lost time*". Also additional spoilage, rework and wage rate "makeup pay" expenses will be incurred during the training period of each new employee.
   (6) Rehiring of employees temporarily laid off. If this is done, the additional costs would include perhaps only items (3), (4), and (5) above. Certain training costs in rehiring could be expected because of the likelihood of transfer of rehired employees to new jobs.
b. Additional service and staff activities.
   (1) Production and Inventory control. Revisions of detailed

schedules of shop orders already issued to the processing departments; reviewing and increasing the "min-max" controls noted on stock records; possible hiring and training of additional production expeditors, clerks, stock handlers, etc.

(2) Purchasing, receiving, inspection, materials handling, etc. Traffic expediting activity is apt to increase; buyers may be required to negotiate revisions of contracts for materials and supplies ordered from vendors—relevant to quantity, price and delivery.

(3) Additional materials handling personnel, inspectors, set-up and maintenance personnel, janitors, etc. are required. The cost of employment and/or transfers of such indirect labor personnel should be included.

c. Added shifts (included only when a change involves an extra shift).

(1) Supervision. If an additional shift of employees is required, new foremen, timekeepers, job leaders, etc. must be provided. Although these employees may be promoted or transferred from the existing shift, new employees must be hired because of the increased workload.

(2) Shift premiums. This incremental cost is obvious.

d. Overtime costs.

There may be some question of the validity of "charging" overtime to the cost of changing production volume levels. Overtime is frequently required for reasons other than a programming decision to increase the aggregate production rate for the next operating period. Various unanticipated delays—material shortages, machine breakdowns, changes in the mix of the workload—all these are causes for sporadic overtime operation to meet the *detailed* production schedules and should not be included. Nevertheless a certain amount of overtime may intentionally be planned for an extended period, and this may be avoidable. (This is likely to be the case in firms having guaranteed annual wage provisions in their contracts with unions because of the stimulus to stablize the number of employees implied by such contract provisions). The amount of overtime costs charged to a decision to increase production level will depend upon the difference between the overtime capacity required under a more stabilized production program, and the amount of sustained overtime occurring because production volume has not been stabilized.

## 2. Costs of decreasing the production level.

a. Unemployment compensation insurance.

The cost of state unemployment compensation insurance premiums varies with the degree of stability of employment at the company, and the laws of the state in which the company is located. The maximum employer's contribution is 1.7% of the employee's annual earnings up to the first $3000. However if the fund accrued in the state repository exceeds a certain stipulated amount and if the average withdrawals from this fund have been low (because of small number of layoffs during the recent past), the employer's contribution may drop to as low as 0.1% of the employee's earnings. Therefore the difference in these premium costs is avoidable if employment can be stablized, and these avoidable costs should be included in the costs of layoffs associated with decreasing production output.

b. Contributions to wage stabilization funds.

Generally, when wage payment guarantees are included, union contracts provide for employer contributions in a manner similar to statutory provisions for unemployment compensation. The employer's contribution stops when the fund has accrued a certain amount. Consequently temporary layoffs cause withdrawals from the fund, and the employer must again incur the additional expense of contributions. The amount of these contributions should be included as a cost of decreasing the production output volume.

c. Other employee costs.

(1) Employee transfers. Union contracts regulate seniority provisions, and may stipulate "bumping" etc. during layoffs. Often such bumping may result in mushrooming effects upon the entire plant force. These transfers require changes in payroll records, personnel records, retraining of employees, additional spoilage and rework costs, etc. Since at least some of this expense is avoidable under a more stabilized production program, an amount should be charged to a decision to decrease the production volume of output.

(2) Plant-community relations. Since union-management relations become somewhat strained after layoffs, the reputation of the company in the community may suffer. Some firms regularly budget expenses for public relations work, including newspaper advertising, gifts to local charities, etc. for the sole purpose of promoting the firm as a "good citizen" of the community. Perhaps such expenses would be incurred whether or not employment was unstable. However, there is an inverse relationship between the community reputation enjoyed by the firm and the number of union contract grievances arising from layoffs, etc. Therefore these expenses, worthy as they may seem in purpose, are at least in part chargeable to the cost of unstable production programs.

(3) Excessive recruiting costs. Closely associated to plant-community relations expenses are excessive costs of recruiting employees because of the reputation for unstable employment at the plant. When a firm must recruit employees from distant communities during periods of no labor shortage in its own community, employment costs are excessive, and these may be avoidable if production output is stabilized.

d. Staff clerical and service activities.

(1) Purchasing. With a cutback in production, purchase contracts must be revised, possibly involving contract cancellation charges.

(2) Inventory and production control. Stock ordering quantities, reordering points, shop schedules and machine loads must be revised, with added clerical and managerial time and expense.

(3) Personnel and payroll expenses. Since temporary layoffs may require separation interviews, personnel record changes. There are additional expenses incurred in the personnel office. In the payroll office, there are expenses involved in closing the payroll records, preparing certificates of eligibility for the state unemployment compensation insurance dividends, etc.

e. Idle time costs.

When work becomes slack in a shop, often there is a lag between the time when employees *should* be laid off and when they are actually sent home. Instinctively a foreman is reluctant to tell a worker to go home because of lack of work. Usually the foreman will try to get shop orders released from the production office, ahead of schedule (but the production control personnel are loathe to release orders because of the activity of revising schedules downward). Hence more delay and more idle time occur. Such occasions are most apt to occur with highly skilled or high seniority employees. To the extent that these idle time costs due to lack of work can be avoided by a more stable production program, these costs should be charged to the decision to decrease the production volume of output.

The off capacity variance in overhead costs, which is computed by the accountant in firms using absorption costing systems, may be considered (partially at least) as a cost of unstable programming of the manufacturing operation.

The common denominator of change in production output rate, to which these costs should be related, is a

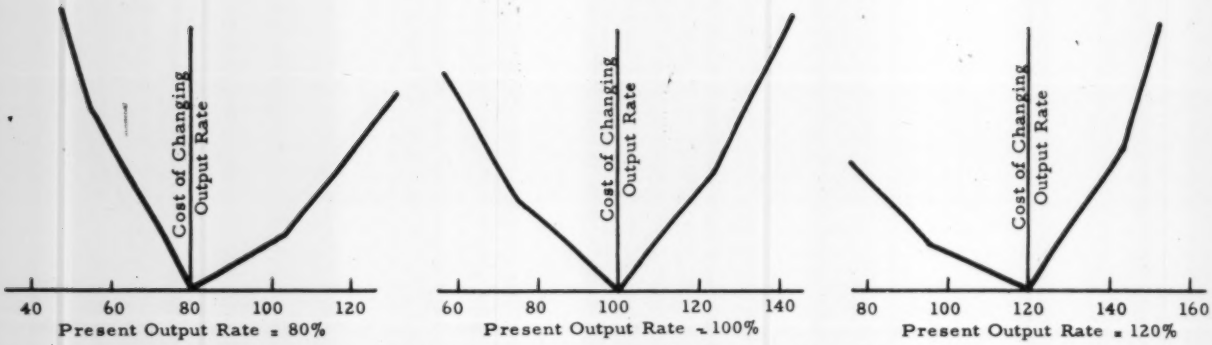
Cost of Changing Output Rate
40 60 80 100 120
Present Output Rate = 80%
Cost of Changing Output Rate
60 80 100 120 140
Present Output Rate = 100%
Cost of Changing Output Rate
80 100 120 140 160
Present Output Rate = 120%

FIG. 1. The Cost of Changing Aggregate Production Output Rate (Linear function assumed).

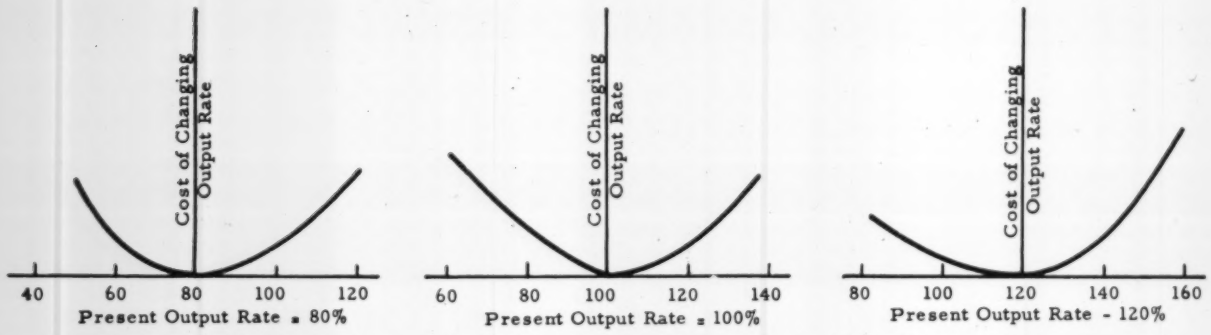
Cost of Changing Output Rate
40 60 80 100 120
Present Output Rate = 80%
Cost of Changing Output Rate
60 80 100 120 140
Present Output Rate = 100%
Cost of Changing Output Rate
80 100 120 140 160
Present Output Rate = 120%

FIG. 2. The Cost of Changing Aggregate Production Output Rate (Quadratic function assumed).

choice requiring discretion. Direct labor hours is probably the best index of measure, especially when there is a large and varying mix of product manufactured, and where the direct labor content in each unit of product is fairly high. Machine hours would be suitable where there is a high proportion of mechanized processing and labor is less influenced directly by changes in output volume. Units of product would be satisfactory where the product mix is stable from one period to the next. The unit of aggregate production rate change is also a matter of judgement of factors in the particular problem. For example, the costs of production level changes could be related to one unit of product, or to 1,000 units of product, to 1,000 direct labor hours, or to 10,000 direct labor hours. This choice will depend upon the frequency of programming decisions and upon the policy regarding the rate of change of production output from one period to the next.

The function relating these costs to changes in output rate would have to be determined empirically in a particular business. Graphically, a whole family of cost curves is necessary to completely define the function. For example, if we specified 100 per cent as the normal output rate achieved by single shift operation, three of the family of cost curves might be represented by Figure 1.

Each present output rate has its own cost function by which the cost of increasing or decreasing present capacity is computed. The assumption of either a linear (Figure 1) or quadratic (Figure 2) relationship between the change in output rate and the costs of the change is necessary if both a *practical* and logical method of programming is to be devised. Perhaps a cubic function may be a better criterion of these costs, but it would be impractical and difficult to use. Note that both sets of curves are asymmetrical about the present capacity. In (7) the authors assumed the quadratic cost function when dealing with the increase in *total* operating costs and inventory costs resulting from production level changes. By differentiating the quadratic equation and minimizing the costs, they were able to derive a simple linear decision rule for programming production and inventories. However, there may be some doubt that the cost function is continuous over the range of possible changes, as they have implicitly assumed. In the linear relationship it is recognized that the costs are discontinuous. For as the magnitude of the change in output rate increases, management usually resorts to *different* means to effect the change, (e.g. introduce a second shift, instead of running more overtime; lay off highly skilled and supervisory personnel, instead of further reduction of semi-skilled operator force). These differences in the methods of changing output rates would cause the cost function to be discontinuous (at least so it would seem). However, whether or not the quadratic or the linear function is correct remains to be seen in the future, after more actual cost data from many firms are

examined.[1] Some assumption is necessary to achieve a workable and rational rule for reaching the programming decision.

## Cost of Excessive Inventories

### *Inventory Costs*

These costs have been described rather extensively in the literature (3), (4). Briefly they consist of the following:

1. Investment charges.
   a. The cost of tying up the additional working capital invested. This cost may be estimated from two different points of view. One viewpoint is that the interest on the money invested should be determined by the average return on the total working capital invested (e.g. operating profits divided by net sales). The other viewpoint is that the cost of investing the working capital should be equal to current interest rates on borrowed capital. The first concept will usually result in higher carrying costs of inventory than the second.
   b. The costs of the risks involved. In stocking products, there are risks of spoilage, deterioration, and of obsolescence. The evaluation of these costs will depend upon good judgment of empirical data.
2. Space charges.
   a. These costs include the out-of-pocket expenses of providing for and administering the storage facility. They include expenses for heat, light, insurance, taxes (or rental) of the warehouse, and depreciation of racks, fixtures, and other handling and storing devices. Generally these costs are apportioned uniformly among the various types of products stored. A more precise method is to apportion these expenses based upon the space or volume of each type of product stored, and the special storage provisions required for each type of product. Obviously the expense of stock handlers and clerks should be allocated to these costs in some equitable manner.
3. Inadequate inventories. As the level of inventory decreases, the probability of running out of stock increases, and the risk of losing customers increases. Therefore a safety allowance or "bin reserve" is kept in stock to prevent those losses. The amount of these reserves depends upon the expected variance of demand during the future period, and upon the confidence in the commitment by the factory to deliver replenishing orders on time. The inventory carrying costs of the safety allowance quantity represents the cost of the risk of running out of stock (4).
4. Order Backlogs. In the case of the firm producing entirely against an order backlog, the cost of an "optimal" backlog would depend upon the expenses of the average unused plant capacity which is maintained to prevent the backlog from growing too high. The cost of excessive backlog would depend upon the operating profit which is forfeited by sub-contracting work ordinarily done in the company's own plant under "normal" backlog conditions. Also there are the costs of business lost from customers who refuse to wait because of excessive backlog.

Inventory carrying costs are expressed as a percentage of the total *direct costs* of the products stored. Fixed costs allocated by accountants to price inventories, should not be included in inventory carrying costs, because they are not part of the *additional* investment in inventory (2).

## Optimal Inventory Levels

If inventory is always maintained at an "optimal" level, there would be zero costs of excessive (too high or too low) inventory. In simple terms, optimal inventory level implies that the stock level is neither so high (or customer order backlog so low) that inventory carrying costs are excessive, nor so low (or customer order backlog so high) that the economic risks of losing customers are more than good management should afford.

Obviously production must take place before inventory is created and customers' demand fulfilled. The end of period inventory depends upon the difference between sales and production during the period (ignoring initial inventory). Whether or not an inventory level is optimal depends principally upon the *future* demand, and since future demands vary, optimal inventory level should vary. Two methods of determining optimal inventory levels are suggested:

a. An empirical analysis of end of period inventories and sales.
b. The average bin reserve quantity plus one-half the economic order quantity for each item stocked, summed over all items.

The first method rests on the assumption that over the past years, inventory levels, on the whole, have been adequately controlled. By computing the ratio of end-of-period aggregate total unit inventory to aggregate total unit sales for the *next* successive period, a standard "stock-sales ratio" can be established for different levels of demand volume. A slightly different version of this technique is described in (5). The relationship between the stock-sales ratio and future sales is shown in Figure 3. Historical data should be used with discretion because certain data will

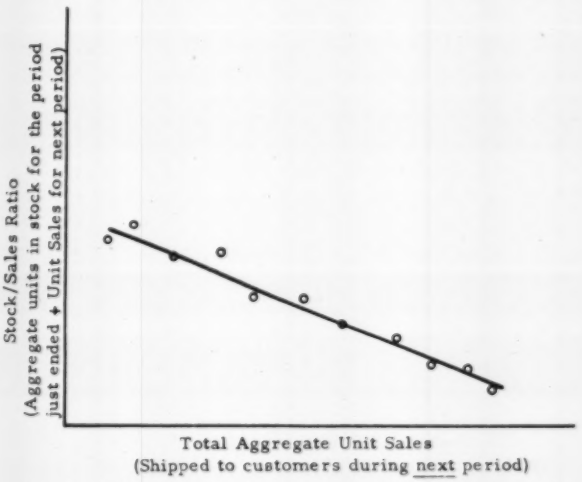
Stock/Sales Ratio
(Aggregate units in stock for the period just ended ÷ Unit Sales for next period)
Total Aggregate Unit Sales
(Shipped to customers during next period)

FIG. 3. A Method of Determining Standard Stock/Sales Ratios from which Optimal Inventory Levels can be Estimated.

[1] Very little information on the nature of these costs is available, so far as is known. These costs are just as important and no more difficult to estimate than inventory carrying costs. More open discussion and exchange of empirical data are needed on the subject of these costs.

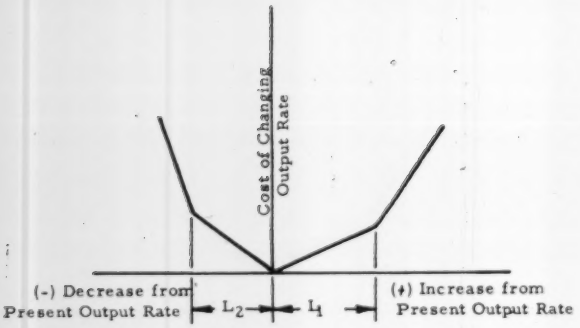


FIG. 4. The Cost of Changing Aggregate Total Production Output Rate versus the Amount of Change from the Present Output Rate.

reflect abnormal circumstances. (For examples, changes in the structure of the distribution system will affect the data; the Korean War period was a period of stockpiling; the years immediately following World War II were abnormal). From such a plot, a standard "stock-sales" ratio can be used to calculate the optimal inventory level, given a sales forecast. This empirical method of determining optimal inventory level may seem too crude for proponents of more logical methods. On the other hand it is simple, and the logical relationship between inventory and forecasted sales is recognized. If good judgement has been used, the results would be adequate as a means for determining the broad programming decision affecting *aggregate* inventories and output rates for an extended future period. (The method is not recommended for within period, detailed production and inventory control.)

The second method of determining the optimal inventory level involves separate consideration of *each item stocked*. By summing the safety allowance quantity stocked plus one-half the economical ordering quantity, for each level of demand, the average optimal inventory level is obtained for each item, for each rate of demand. If there is a large mix of products involved, this method is time consuming. Furthermore, economical manufacturing ordering quantities determined by the familiar formulae are of questionable logic because the formulae consider each product independent of others, hence detailed production scheduling of all products becomes virtually impossible. This is very well explained in (6).

The choice of the method of computing optimal aggregate inventory level is left as a matter of judgement in the particular situation.

## PART II

### Determining the Optimal Production Program

There is a growing amount of literature describing methods of determining optimal production programming decisions. Most writers have used a method of linear programming to minimize the *total* production and inventory costs, assuming a certain *fixed* level of employment is optimal policy, (2), (8). The use of a linear decision rule for production has been proposed by Holt, Simon, and Modigliani in (7). In many of these papers, the authors are concerned with programming production over several time periods in the future. In such a problem, the total out-of-pocket costs of production output and inventory may both increase and decrease with respect to the time periods considered. This is most probable when aggregate sales demand is both increasing and decreasing in successive periods.

In this discussion, attention is given exclusively to those costs which increase with a change in production output rate from one period to the next. The programming decision has to be computed before *each future* period. The costs considered are only those incurred as a result of a decision to change from the *current* aggregate production output rate and/or to deviate from the optimal aggregate inventory level desired at the *end* of the *future* period. If there is *no* change in the output rate from the present period to the next, no costs of change have been incurred, but there may be costs of *not* having an optimal level inventory incurred. The costs considered here are dependent solely upon the magnitude of change in aggregate rate of production *and* the magnitude of the difference between actual inventory and optimal inventory. The method starts with the present output level and permits a change in employment level *and* a change in aggregate inventory level, such that the sum of the costs of these changes is minimized.

Graphically the costs of changing aggregate production output rates are as shown in Figure 4.

An increase from zero to $L_1$ represents a change involving hiring or rehiring, training costs, plus other costs previously described. In this instance such an increase would *not* involve overtime, or additional shift operations. An increase greater than $L_1$ would result in the costs increasing more sharply because overtime and/or additional shift would be required to affect such an increase in output rate. A decrease from zero to $L_2$ would involve routine layoffs, or perhaps a work week of less than forty hours. A decrease greater than $L_2$ would involve laying off key operators, highly skilled, and perhaps supervisory personnel who are difficult to replace. Note that the costs of production rate changes are asymmetrical about the origin. This plot would be repeated for a whole family of different, present output rates, so actually this single plot is merely representative of a family of similar curves. Some curves in the family may be relatively flat, while others might be steep, depending upon the costs in a particular situation.

Figure 5 shows the costs of carrying excessively high or low inventory. In this case it is assumed that some optimal positive stock must be carried, hence the curve intercepts the ordinate at a value greater than zero costs. It is also assumed that no change in warehouse space is required over the range of deviations from optimal stock level

shown. This plot is asymmetrical about the origin because it is assumed that the penalty costs of too much inventory are less than the costs of too little. Again this plot is representative of a family of similar curves plotted for each optimal level for each rate of sales demand.

### The Linear Program

Referring to Figures 4 and 5, let:

$c_1$ = cost of increasing production output rate during the program period $t$, such increase *not* requiring overtime or an additional shift, i.e. such an increase is less than $L_1$. $c_1$ is assumed to be the slope of the linear function in Figure 4, between the values of zero and $L_1$.

$c_2$ = cost of an increase in production output during period $t$, such increase being greater than $L_1$. $c_2$ is the slope of the linear function in Figure 4, for changes in output greater than $L_1$.

$c_3$ = cost of decreasing production during period $t$, such decrease *not* involving extensive layoff, but perhaps a reduced work week, and the amount being less than or equal to $L_2$. $c_3$ is the slope of the linear function for changes in production rate between the values of zero and $L_2$.

$c_4$ = cost of decreasing production such that the decrease is greater than $L_2$ and does involve extensive layoff of numerous skilled personnel, difficult to replace and retrain. $c_4$ is the slope of the linear function for decreases in output rate greater than $L_2$.

$c_5$ = cost of carrying one unit of product (aggregate average unit) in inventory in excess of optimal level during period $t$. $c_5$ is the slope of the linear function in Figure 5, showing the cost of too much inventory.

$c_6$ = cost per unit (aggregate average cost) of carrying inventory at a level less than optimal. $c_6$ is the slope of the linear function in Figure 5 showing the cost of inadequate stocks.

The dimensional unit of $c_1, \cdots c_6$ may be any convenient measure, e.g. dollars per 100 aggregate units of products; dollars per 1,000 man hours of production; dollars per $1,000 worth of production output, etc. The values of $c_1, \cdots c_4$ would be different for various initial output rates; values of $c_5$ and $c_6$ would be different for each level of forecasted sales. In other words different cost functions would be used. Obviously the numerical values of $c_1, \cdots c_4$ would be considerably greater than values of $c_5$ and $c_6$, expressed in equivalent terms.

Let: $t$ = the time period between successive programming decisions, usually the period over which the market forecast is assumed to be "fixed", to the extent that broad commitments on employment levels, purchase agreements, etc., are made. This period could be a month, a quarter, a marketing season, or even a year. $t-1$ represents the current period about to end; $t$ is the next future period; and $t+1$ is the second period in the future.

$P_t$ = Aggregate units of production output during $t$.

$S_t$ = Forecasted aggregate units of product to be shipped to customers during $t$.

$I_t$ = Finished goods inventory in aggregate units, as of the end of period $t$ (the next future period).

$I_o$ = Optimal level of inventory at end of $t$. For purposes of this illustration it will be assumed that $I_o = I/S\,(S_{t+1})$ where $I/S$ is the stock/sales ratio derived empirically from past operating data, as previously described.

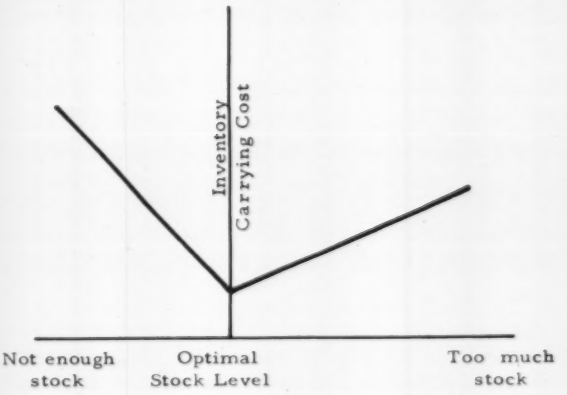


FIG. 5. The Cost of Carrying More than and Less than the Optimal Aggregate Total Finished Stock to Support the Next Period Operations (Linearity assumed).

$P_t - P_{t-1}$ = Change in production output, from the present rate $P_{t-1}$ to the next period of operation. The solution of the linear program will give the optimal *amount of change*, from which the production output for next period is easily calculated.

$I_t - I_o$ = Deviation from optimal inventory level. The program solution will indicate this deviation, from which the end of period inventory can be estimated.

For convenience in programming notations, let:

$$
\begin{aligned}
X_1 &= (P_t - P_{t-1}) \text{ if } 0 < (P_t - P_{t-1}) < L_1\,, \\
&= L_1 \text{ if } (P_t - P_{t-1}) \geq L_1\,, \\
&= 0, \text{ otherwise;} \\
X_2 &= (P_t - P_{t-1}) - L_1 \text{ if } L_1 \leq (P_t - P_{t-1}), \\
&= 0, \text{ otherwise;} \\
X_3 &= (P_t - P_{t-1}) \text{ if } L_2 < (P_t - P_{t-1}) < 0, \\
&= L_2 \text{ if } (P_t - P_{t-1}) \leq L_2 \\
&= 0, \text{ otherwise;} \\
X_4 &= L_2 - (P_t - P_{t-1}) \text{ if } L_2 \geq (P_t - P_{t-1}) \\
&= 0, \text{ otherwise;} \\
x_5 &= (I_t - I_o) > 0 \\
x_6 &= (I_t - I_o) < 0
\end{aligned}
\qquad (1)
$$

The objective of the linear program is then:

$$\text{Minimize: } c_1x_1 + c_2x_2 + c_3x_3 + c_4x_4 + c_5x_5 + c_6x_6 \qquad (2)$$

The objective of the program is to minimize the marginal costs of changing the production output rate from its present level to the level required for the next period. The cost of this change is assumed to be valid over the range of changes in output rates described in Figure 4. In other words, if an increase in output rate $x_2$, greater than $L_1$ is required, the total marginal costs of the change would be $c_1L_1 + c_2x_2$. For example the cost of rehiring employees to bring the output rate up to a full single shift capacity would be equal to $c_1L_1$; then further increase in output rate is achieved by operating overtime, or running a second shift, the costs of which are represented by $c_2x_2$. Thus Figure 4 represents the "marginal cost path" which must be followed in order to execute any increase or decrease in production output rate.

The following restrictions must be recognized:

1. Maximum capacity output rate attainable, including three shift operations, temporary sub-contracting, etc. Call this $K_1$ in terms of symbols of the program:

$$x_2 + P_{t-1} \leq K_1 \tag{3}$$

2. Maximum rate of increase which can be affected during period $t$, limited perhaps by the *rate* at which new or rehired employees can be trained to be effective; or perhaps the *rate* at which suppliers can boost delivery of additional materials and supplies, during the next period. Call this $K_2$.

$$x_2 \leq K_2 \tag{4}$$

These two restrictions would not operate simultaneously for the same programming decision. Either one would be effective for a particular program.

3. Forecasted Sales demand will be met, i.e.

$$S_t = I_{t-1} + P_t - I_t \tag{5}$$

Since we are dealing in terms of *change* in production output rate, and deviations from optimal inventory, this restriction must be expressed in these terms.

If $S_t = I_{t-1} + P_t - I_t$,

Then $S_t - S_{t-1} = (I_{t-1} + P_t - I_t) - (I_{t-2} + P_{t-1} - I_{t-1}) = P_t - P_{t-1} - I_t + 2I_{t-1} - I_{t-2}$.

Let: $2I_{t-1} - I_{t-2} + K_3 = I_o$ when $I_o = I/S\,(S_{t-1})$;

or $K_3 = I_o - (2I_{t-1} - I_{t-2})$

Then: $S_t - S_{t-1} = P_t - P_{t-1} - I_t + I_o - K_3$.

But $P_t - P_{t-1} = x_1$ or $x_2$ or $x_3$ or $x_4$,

and $-I_t + I_o - K_3 = -(x_5 + K_3)$ or $-(x_6 + K_3)$

Therefore the restriction that sales demand must be met may be written:

$$x_1 + x_2 + x_3 + x_4 - x_5 - x_6 \geq S_t - S_{t-1} + K_3 \tag{6}$$

4. The solution of the program should contain non-negative answers, i.e.

$$x_1, x_2, \cdots x_6 \geq 0 \tag{7}$$

The method for solving this linear program is clearly described in (9).

A particular application of this model would not necessitate the use of all variables $x_1, x_2, \cdots x_6$. If $S_t > S_{t-1}$ and $K_3 > 0$ then $x_3 = 0$, $x_4 = 0$, $x_6 = 0$, and would *not* be included in the model for the particular program. In this situation the program would be defined as follows:

Minimize: $c_1x_1 + c_2x_2 + c_5x_5$

Subject to: $x_2 \leq K_1 - P_{t-1}$

$x_2 \leq K_2$

$x_1 + x_2 - x_5 \geq (S_t - S_{t-1}) + K_3$

$x_1, x_2, x_5 \geq 0$.

On the other hand, if $S_t < S_{t-1}$ and $K_3 < 0$, then $x_1$, $x_2$, $x_5 = 0$ and would be excluded from the program. The program in this situation becomes:

Minimize: $c_3x_3 + c_4x_4 + c_6x_6$

Subject to: $x_3 + x_4 - x_6 \geq (S_t - S_{t-1}) + K_3$

$x_3, x_4, x_6 \geq 0$

If $S_t < S_{t-1}$ and $K_3 > 0$, then $x_5 = 0$, but the program model should contain $x_1, x_2, x_3, x_4, x_6$. Or if $S_t > S_{t-1}$ and $K_3 < 0$, the model should contain $x_1, x_2, x_3, x_4, x_5$.

After solving for the optimal values of $x$, the actual production and inventory program can be computed from equations (1).

The effect of $K_3$ upon each successive program is to apply a "correction factor" for errors in previous forecasts and deviations from optimal inventory resulting therefrom. In other words the interactions among the production rates, inventory levels, and sales forecasts necessitate a continuing process of compensation and correction. Interactions between detailed production scheduling and inventory control decisions (during the period), are also reflected in $K_3$. It is necessary to account for these interactions, otherwise the system would become "dynamically unstable", or hopelessly out of control. The linear program thus provides for the corrective action by compensating for errors of past programming and detailed scheduling decisions.

Since the incremental costs of changing production rates are in most cases considerably greater than the costs of deviations from optimal inventory, the linear program should provide for reasonable stability of production output rates, and thus employment. This is a desirable objective. At the same time the program will specify changes in output rate when such changes are required by the constraints described.

The method advocated here may be criticized because a decision for *next* period's production and inventory should involve consideration of forecasted sales many periods in the future. Indeed this is a valid criticism, *if* the precision and accuracy of future sales forecasts are known with a high degree of certainty. If sales forecasts become less reliable as they are projected further into the future, then decreasing weights must be arbitrarily assigned to their influence upon the current decision. In practical situations, the production programming decisions should (and probably would) be determined *each time* new sales forecasts were received. Whether or not this method is less valid than others proposed in (2), (7), (8) can only be proved by comparison of the results achieved in an actual situation.

Obviously the validity of the results of this program depends entirely upon the values assigned to $c_1, c_2, \cdots c_6$, $S_t$, and $S_{t+1}$. All other numerical values are readily available from records of today's firms. Like all linear programs one of the chief values of using this model lies in the fact that it forces management to express the costs of important decisions, *before* the decision is made. Moreover it enables management to use a logical consistent method for making a complex decision, instead of intuitive methods, which are apt to be costly because of their inconsistency.

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Inquiries received indicate that many sources of employment information are seldom tapped. These include: The United States Employment Service, Civil Service, Universities and Colleges of past enrollment, technical trade publications, classified ads in newspapers of the desired area, technical employment agencies (employer pays the fee in most cases), and many others. Much of this information, including books on how to prepare resumes and conduct employment contacts, is available at your local library. Use all these services in determining the best opportunities. Space will not permit listing all positions and men available, but each inquiry will be given confidential and individual attention. Direct your correspondence to Malcolm M. Kreske, P. E., Chairman, I. E. Opportunities Committee, American Institute of Industrial Engineers, Inc., 145 N. High Street, Dept. OP, Columbus 15, Ohio.

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# Expanding Industrial Research

**By Walter S. Buckingham, Jr.**

*Research Economist, Engineering Experiment Station, Georgia Institute of Technology*

One of the most striking aspects of American economic development in the last few years has been the enormous expansion in the field of research. Until the end of the nineteenth century virtually all scientific research was done in England and Continental Europe. As a consequence, there have been, until quite recently, relatively few truly basic scientific discoveries coming from the United States. In general, the American contribution to technological development has been more distinguished in the practical or applied fields than in the more basic theoretical sciences. In this country, however, there has been a growing awareness, especially in the last fifteen years, that research is the key to economic progress.

Research has grown from less than $1 billion in volume annually immediately before World War II to over $5 billion in 1955. Two tendencies can be observed in this growth. One is an increase in the amount of research by private industry (particularly the largest firms), as compared to that done by government. This does not necessarily indicate any reason to expect private industry research to replace that done by government agencies. In fact, the great increase in private research actually causes a greater need for some types of government research because of the competitive nature of our economy. Since only the largest firms can afford substantial outlays for research, most of the private research work is done by a few firms in relatively few industries. The result has been that productivity in manufacturing (where the largest firms dominate) has been increasing at a rate of 3½ to 5 per cent per year for many years, while that in agriculture and other fields characterized by small producers has increased far less. An increase of 2 per cent per year in the productivity of agriculture is typical, and in many services and distribution trades productivity is not increasing at all.

The growing gap between the productivity of big-firm industries and the rest of the economy puts the medium and small producers at an ever-greater disadvantage in their struggle for the consumer's dollars. Although research needs vary among firms and industries, it is generally agreed that in a competitive industry 2 per cent of gross income should be spent on research to develop new products, processes and methods of organization. Most southern firms have not invested to this extent in research and hence have been handicapped. Medium and small producers who do not actively engage in research soon become relatively less efficient. They cannot pay as high wages as the industrial giants; they cannot get control of their own raw material supplies; and they cannot afford to develop the new products upon which the largest profits can initially be made. Thus they are forced to rely either on cooperative research ventures or on governmental research, as agriculture has traditionally done.

The second current trend in research is an increase in basic or pure research, as contrasted to applied research. Basic research now accounts for more than 5 per cent of all industrial research expenditures, as compared to only 1 per cent in 1936. Since the dollar volume of research expenditures has increased about 500 per cent in the last 20 years, this would indicate an increase in expenditures on basic research from about $10 million to $250 million. Assuming that prices have somewhat more than doubled since 1936, this is still an enormous increase in basic research—possibly an increase of over ten times.

There has been a growing recognition that basic research is practical, even though the results may not show up immediately in profits to the sponsor. A great deal of basic research is often necessary before fruitful applied research can be undertaken. Both theoretical and empirical research are usually necessary. Many firms are faced with serious problems which simply cannot be solved without both the development of new theoretical tools and the accumulation of large amounts of empirical data. An entirely new framework is often necessary for studying the problem. Therefore, it is necessary for business firms to cooperate in the undertaking of the research, because the results will benefit all who are faced with similar problems. Fortunately there has been a rapid growth in this area. There are now eight non-profit, cooperatively owned consulting research laboratories in the country and many other cooperative research ventures within specific industries.

Increased use is also being made of university facilities for industrial research. There are more research organizations of this type than any other, either private, cooperative, or strictly governmental. Many advantages come from the use of university research facilities by industry. Full-time research specialists, part-time research associates from the teaching faculty, and graduate students are all available. In addition, education and research complement each other to the end of raising the standards of both when they are combined.

## Research and Industrial Development

Research is both a cause and consequence of industrial development. Research leads to innovation, which includes inventions and improvements in techniques, products and organization. Innovation creates economic surplus by giving the innovator a competitive advantage. This surplus can be, and usually is, invested in part in more research. Thus a cumulative process of growth and expansion can be generated by the application of scientific methods and techniques to the solution of industrial problems.

It is not surprising that the initial developments in research were confined largely to experimentation with physical objects, movement, energy and their interrelationships. These subjects lend themselves especially to systematic investigation. These subjects can be observed, or the evidence of their existence can be examined. Their properties and movements can be carefully calculated, and the conditions under which the research occurs can be rigidly controlled. Hence the predictions which can be made from the conclusions of the research are likely to be accurate to a high degree. Because of this predictive accuracy, scientific research enjoys the highest of reputations in the modern world.

Research and scientific methodology are no monopoly of the physical sciences, however, In fact, scientific research in the area of physical objects and techniques has led to the necessity for research in other areas. The unprecedented industrial development to which the earlier physical research led now requires such an elaborate and complex system of organization for proper management that research methods must be applied in areas outside that of the so-called physical sciences. Otherwise the gap between the levels of technological development and effective technological application widens to such an extent that there is a large and needless waste of all kinds of resources. The further widening of this gap, if carried to an extreme, could lead to dangerous and irresponsible uses of technical knowledge.

Mass production techniques developed early in this century have accelerated the need for research in areas involving human activity. The great increase in investment per employee, the quantity and intricacy of goods which can be produced to compete for the consumer's preferences, and the installation of automatic machines which require almost continuous operation of factories, all accentuate human problems and make the need for further research more important than ever before. As machines and complex processes replace men in industry, the human factor becomes more, not less, significant. People must work under greater pressures, assume more responsibilities, and use greater skills. The cost of human failure, of social disorganization, and of maladjustment become greater, both to the individual firm and to society. Social and economic research are no longer luxuries but necessities. They may mean the difference between the success or failure of the business firm.


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The development of mass production technology has also led to an enormous growth and concentration of industrial enterprises. The increase in the size of business organizations was accompanied by large profits which could be reinvested in research and which could be used to force competitors to do likewise. This growth and concentration has produced a high degree of interdependence among all major sectors of the economy. Business operation has consequently become vastly more complex. It is no longer possible for a business executive to know all of the details of his firm's operations. The large number of variables facing the firm because of the interrelationships in the economy and the speed with which these variables change have made it impossible for a modern firm to survive by relying on traditional methods or techniques of doing business. The businessman of today can no longer safely depend on his intuition, "vision", or even the accumulation of vast personal experience, to guide him in making sound decisions. Often the "obvious" or "common sense" solution to a problem turns out to be the wrong one and leads to disastrous results. The recent growth of "Operations Research", of reliance by management on expert staff advisors, and of the functional separation of policy making from policy administration, are all evidence of a growing rationalization of business operations.

Research has become increasingly necessary as specialization in management has followed the growth of a high degree of division of labor in the productive process itself. It is necessary for decisions to be made by groups of highly specialized individuals who, in turn, are forced to rely heavily on the reports from many specialized, functional departments. Since there can be only a few people who are in position to supervise the entire operation of the firm, it is all the more important that the facts communicated to this central decision-making body be as precise and accurate as possible. There can be no substitute for scientific research in providing the proper basis for intelligent decisions in this kind of situation.

### Newer Research Needs

For all these reasons, the great growth of both basic and applied research in the physical science must be balanced in part by increased research in other areas. It is imperative that the management of industry be governed by a sound understanding of the principles of economics, psychology and sociology, as well as by an insight into purely technological problems. The study of these subjects in the light of industry's requirements has received considerable attention in the recent past, but relatively speaking, the surface has hardly been scratched. It would probably be difficult to overstate the ultimate benefit which will result from basic studies of factory organization, productivity, communications, management decision making, manpower availability, personnel training and placement, safety, marked evaluation and prediction, and related activities.

A useful classification of research can be made on the basis of its subject matter. First is that research which is concerned with physical objects and forces. This is usually a function of the physical sciences and of engineering. It was referred to above as having created a great need for further research in the areas included in the second and third groups below.

The second group of subjects for research comprises those which deal with people in their relationships with physical things. This would include studies of factory organization, quality control, productivity and efficiency, sampling, manpower placement and training, safety, and some aspects of economics and communications.

The third group consists of the area of research which is concerned with people alone. Included here are market research, industrial relations, psychology, some aspects of economics, business and personnel organization, and management decision making.

No well-rounded research program can limit itself to the first group mentioned here. Even purely physical research in such areas as chemistry, physics and astronomy is likely to be wasted unless the human problems involved in the development, application and organization of results can be solved. It is estimated that today the application of inventions, for example, cost over ten times as much as the original inventions themselves. Many of these high costs of application are due to bottlenecks in production that are human rather than physical. Government inventions are free but seldom used simply because the development and application problems have not been solved and hence these inventions are not economically feasible. Thus, not only are there many human problems associated with the application of physical research, but often these human problems must be solved before the physical research is of any use at all. Those firms which have not recognized the importance of research in the areas of human problems and organization may well be driven to such recognition if they are to survive in our rapidly changing economy.


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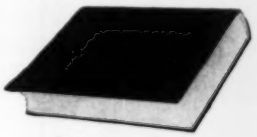

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# Job Design Research

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In two previous articles (1, 2) the subject of Job Design, i.e., the process of designing job content (as distinguished from methods design), was introduced, and current practices and the need for research on this important problem were indicated. Following a brief review of the previous material, a recent research study specifically designed to test the effects of modifications in job content on productivity, quality and job satisfaction will be presented. In addition, two other studies are reviewed to help indicate the scope and complexity of the problem area.

## Trends in Job Design

Very recently a number of organizations have begun to experiment with changing the content of jobs in the direction of specifying job content having greater complexity, containing a longer sequence of tasks, requiring greater skills, permitting rotation between tasks, and having greater responsibility for inspection, for setting up and maintaining equipment and for controlling production rates. This development, known as job enlargement, has been received with great enthusiasm by the public, press, and business community (3, 4, 5, 6).

The results flowing from job enlargement programs that have been undertaken are not those that could have been anticipated when the bases of prediction are the classic methods of job specification through job fractionation. The results reported indicate apparent gains in productivity, quality, morale, job satisfaction, and so on. The gains may be explained—although this has not been done—by a resolution or lessening of conflict existing between the individual's motivational forces and his assigned work. Such a conflict has been observed to exist in many instances. When present, this conflict may have a deleterious effect upon productivity, costs, morale, and social organization.

The implications of job enlargement are of great importance because of the indicated challenge to the heretofore inviolate principles of specialization and functionalization. Currently, however, serious students of management, production, and human relations may feel that it is much too premature to consider job enlargement as an antidote for the ills of highly specialized jobs, typified by the assembly line. Still needed are theories of job design carefully evaluated by experimentation to produce principles to guide job designers in specifying the content of jobs and to predict accurately the consequences of their designs.

Considerable study has been undertaken and a large body of knowledge exists concerning the design of job methods; so much so that a specialized professional branch of industrial engineering, called methods engineering, has become devoted to it (7). On the other hand, relatively little information has been available concerning the design of job content.

Two years ago a survey (2) was undertaken to obtain information regarding the manner in which American industry designs jobs as to their content. The study sought to determine:

1. The decisions made in the process of designing jobs.
2. The precepts, principles, intuitions, and other guides used in making these decisions.
3. Where in the production planning process these decisions were made.
4. Who was responsible for making decisions concerned with the design of job content.

As to the question of who is responsible for the design of jobs, the survey indicated that line foremen or supervisors always had the responsibility for job design in about one quarter of the cases, and the engineering department always had the responsibility in about one quarter of the cases. The foreman sometimes had the responsibility in about 30% of the cases, and the engineering department sometimes had the responsibility in about half the cases. The personnel department sometimes had the responsibility in about one quarter of the cases, and in about 70% of the cases never had the responsibility.

As to precepts or principles used in job design and where in the production planning procedure jobs are designed, the survey revealed the following information:

1. The job design process is centered around the phase of manufacturing planning concerned with the planning of separate operations in the production sequence.
2. No systematic methods of job design can be said to exist.
3. No methods for evaluating the effectiveness of job design can be said to exist.

4. Of overwhelming influence in the design of industrial jobs is the criterion of minimizing immediate cost of producing, i.e., the immediate costs of performing the required operations. The usual indicator of satisfying the criterion is minimum unit operation time.

Designers of jobs see the criterion of minimum cost (or immediate cost) of producing as being satisfied by the application of the following precepts or guides for specifying job content:

1. The content of individual tasks comprising a job is specified so as to:
   a. Achieve specialization of skills.
   b. Minimize skill requirements.
   c. Minimize learning time or worker training time.
   d. Equalize and permit the assignment of a full workload.
   e. Provide for worker satisfaction (no specific criteria for job satisfaction are known to be in use).
   f. Conform to the requirements of layout of equipment or facilities and, where they exist, of union restrictions on work assignment.
2. Individual tasks are combined into specific jobs so that:
   a. Specialization of work is achieved whenever possible by limiting the number of tasks in a job and limiting the variations in tasks or jobs.
   b. Content of a job is as repetitive as possible.
   c. Training time is minimized.

Engineers and industrial managers have been the doers concerning job design. As such, they have determined the nature of jobs for large segments of business and industry. The concepts of job design held by them, and the concepts advocated by economists, have exerted an exceedingly strong influence. These concepts are centered around specialization of labor, minimizing skills, and minimizing immediate production time. They are based upon limited criteria of minimizing immediate cost or maximizing immediate productivity. Thus, job design is based upon the principles of specialization, repetitiveness, low skill content and minimum impact of the worker on the production process.

Social philosophers have long pointed out the consequences of current job design concepts. They have decried the dehumanizing aspects of repetition without mental activity, of absolute conformity to job descriptions, of methods and standards lacking challenge, without intellectual activity, and without expression of needs and aspirations except through other channels. They would like to know the consequences, for democratic society, of rigidly imposed jobs, completely described, requiring absolute conformity, prohibiting challenge of the status quo, and resulting in utter dependence for satisfaction of needs and aspirations on superiors in the hierarchy. Many serious social scholars see the consequences to be antidemocratic in their effects. Perhaps it is too early in the history of our industrial society to be able to predict whether the worker subjected to such a life experience can also be an effective and responsible citizen of a free democratic society.

Serious students of management and organization are not completely wed to the traditional concepts of job design. They have questioned the application of specialization that requires the human being to function as a single purpose machine tool. They ask whether or not this may lead to inefficiency in the form of fatigue, stresses and strains. Concern is expressed over the design of jobs that have little inherent interest, challenge, or meaning (except monetary) (8, 9). It has been said that the division of labor has been overdone, resulting in specialization far beyond the degree necessary for efficient production. While there is some evidence to support this, (10, 11) little or no experimentation with the variables that underlie effective job design has been undertaken in the half century since the rationalization of production.

According to Drucker (12), there is concrete but fragmentary evidence that the use of the worker as a single-purpose tool is wasteful, unproductive, and an inefficient use of man in the production process. It is poor engineering. It leads to tension, frustration, and dissatisfaction. Drucker summarizes this as follows:

> The principle of specialization is productive and efficient. But it is very dubious, indeed, whether we yet know how to apply it except to machinery. There is first the question of whether "specialization" as it is understood and practiced today is a socially and individually satisfying way of using human energy and production—a major question of the social order of industrial society.

Some of the current concepts which are characterized by conflicting precepts and goals are summarized by Drucker (13).

> The industrial engineer sees in the human being a tool and that means that, to him, the human being is the more productive, the more thoroughly his work has been set up and laid out *for* him. The social scientist lays stress on man's need to participate. He, therefore, concludes that the human being is the more productive and the more efficient, the more *he himself* designs and lays out his own work (13).

### Research Results—Walker

Walker (14) has indicated that he believes "we are only at the threshold of a scientific understanding of man's relation to work and especially his relation to the new technological environments within which much of the work of the modern world is being performed."

Aside from the early work under the British Medical Research Council, there has been relatively little research on the relationship between job content and productivity (quality and quantity of work produced), morale, job satisfaction, and long term economic cost. A great deal of research has been, and is, going on which is concerned with the effect of surrounding variables and conditions on productivity, satisfaction, etc. Omitted from consideration here are the various trial and error attempts, popularly known as job enlargement, that have been undertaken by a number of companies (15) in their efforts to overcome the consequences of completely "engineered" job designs. While we do not question the good intentions underlying these efforts, we would like to address ourselves to investigations carried out under controlled conditions.

Three significant research projects on job design are presented here to illustrate the complexity of the problem area, the variety of research interests, the variety of investigational methods that are being brought into use, and the different concern shown for the variables that are operating. Each project is concerned with job content and job design, and in its own way is a pioneering effort that provides needed research data.

The work of Walker and Guest at the Institute of Human Relations, Yale University, has had a major impact on the problem area by proving interest and impetus for examining the effects of job design on boredom, motivation and job satisfaction. It is one of the first thoroughly organized and systematic investigations into the consequences of job specialization. The detailed research findings have been reported extensively (9, 11, 16).

The study took the form of surveys of jobs in automobile assembly plants and was devoted to an examination of the effects of mass production technology on job satisfaction and human relations of workers on the assembly line. It was an exploration of workers' experiences, as gathered through depth interviews. The highlights of this study are summarized in the following material.

Mass production technology has evolved the following principles which have been characteristics of the method wherever it is applied:

1. Standardization.
2. Interchangeability of parts.
3. Orderly progression of the product through the plant in a series of planned operations at specific work stations.
4. Mechanical delivery of parts to work stations at the right time and mechanical removal of assemblies.
5. Breakdown of operations into their simple constituent motions.

To apply these principles, the engineer translates them into job designs for individual workers. The individual job designs flow from the establishment of job cycles which specify the work methods, tools and the prescribed number of operations to be performed by a worker in a given time period, or in the case of those working on moving conveyors, within a given distance on the belt. The result of such specification results in jobs that, on the average, have the following characteristics:

1. Mechanical pacing of work (particularly on the main assembly line).
2. Repetitiveness.
3. Minimum skill requirement.
4. Predetermined specification of tools and methods.
5. Minute subdivision of product worked on.
6. Severe limitation on social interaction.
7. Surface mental attention.

With these characteristics identified, the study proposes to examine the consequences of such job designs in terms of the effects on individual workers, and the gains and costs to the company. The consequences can be divided into both social and economic gains and costs. Looking first at the gains, the "engineered" job has yielded high levels of output per man-hour at low costs, providing profits for the company and giving the public a relatively low cost product. In view of these contributions, the engineer and manager feel that they may rightfully ask, "Should not this be sufficient justification for any social costs that may be incurred?" Unfortunately, once we attempt to answer this question we are ensnared, for this is not the question with which we are concerned. We accept the concept that low unit cost production is perhaps the fundamental requirement for the progress made by our industrial society. However, what we are concerned with is the method of achieving low unit cost production. So our question should be: "Is the method of designing jobs chosen by the engineer the optimum one for achieving low unit cost production or minimum total economic cost, which by definition includes social costs?"

An examination of the social costs indicates some significant and disturbing effects. All of the effects add up to the simple fact that workers on mass production jobs despise their jobs. This dissatisfaction with the job is not due primarily to what is usually considered important to a job, for the pay, security, working conditions, pension plan, supervision, etc., are seen to be good. What, then, are the consequences of these job designs that lead to this dismal result? These may be grouped into two categories as follows:

1. Those leading to the anonymity of the individual worker, which we have previously called minimizing the impact of the worker on the organization. The anonymity results from designing out of the job virtually everything that might be of real, personal value to the worker.
   a. The worker has no control over his *work pace* and rate of production.
   b. His job is highly *repetitive*, having been broken down into the simplest motions possible.
   c. There is little or no need for *skill*, because of the simple movements required.
   d. His job is completely specified as to methods and tools. He has *no control* over these or any changes introduced.
   e. Because he never works on more than a small fraction of the product, he has *no identity* with the product and does not see the final results of his work.
   f. He has *no identity* with the process and cannot estimate his contribution to it in terms of quality.
   g. The demands of the job require *only surface attention* on his part. Some attention is required but not enough to allow him to become really absorbed in his work.
   h. The geographic arrangement of the production line severely limits his social interactions. Men on the line work as individuals, having no identification as a work group. The *lack of group awareness* appears to reinforce the sense of anonymity.
2. Those leading to the depersonalization of the job, in that there are no means for job progression vertically through a series of distinct steps. Simplified tasks have all but eliminated skill differences from one job to the next. Very few workers in the study had experienced any substantial change in job classification during a period of 12 to 15 years.

The effects on the individual resulted in strong dissatisfaction with the job and frustration of aspirations because of the lack of progress or advancement. As a consequence,

there were some serious economic costs for the company. Turnover was high. Quality performance was not maximized because of inherent lack of interest in the job. Labor-management relations were in a state of constant tension.

### Research Results—Marks

The second research project to be examined represents one of the first controlled experiments on job design in an industrial plant. An experimental investigation of the effects on some measures of economic productivity stemming from alteration of the design of jobs was conducted by A. R. N. Marks (17) for his doctoral dissertation under the primary direction of the authors.

The specific purpose of the study was to explore the conditions under which improvement in productivity could be expected from change in the content of a job. A set of hypotheses was derived which is paraphrased below.

Higher economic productivity will result from modifying work content of a job in the direction of:

a. Increasing the number of tasks in a job;
b. Putting together tasks that are similar in technological content and skill demands;
c. Putting together tasks that are sequentially related in the technical process (process = complete systematic sequence of events or operations required to produce an item, part or complete product);
d. Putting together tasks that include final activities in the process or sub-process;
e. Putting together tasks that increase worker responsibility, e.g., that enlarge the area of decision-making in regard to work rate, methods, set-up, etc., and the area of autonomy in regard to quality, material supply, etc.;
f. Putting together tasks that increase the opportunity for the worker to perceive the relationship of his contribution to the completion of the work process.

These hypotheses were used broadly in the experiment as guides for modifying jobs. Because of the nature of the industrial situation, their individual effects upon selected dependent variables could not be analyzed separately.

With all the attempts to avoid it, we still seem to have developed a special language, and it may be helpful if we define some terms as follows:

1. *Economic productivity* may be defined as direct productivity modified by the addition of appropriate "overhead" or hidden charges, e.g., those relating to costs stemming from absenteeism, labor turnover, quality requirements, scrap, etc.

2. *Job* is defined as the structure of the tasks and work methods and the setting in which they take place. The content of a job may be considered to be the sum of the work content, methods content, organizational content, and personal content, plus their interaction.

3. *Work content* is the assigned series of tasks which grow from the requirements of the technical process.

4. *Methods content* is the design of the ways in which the work activities are to be performed. It is often referred to as methods design.

5. *Organizational content* is the organizational setting of the work situation in which the assigned tasks are to be carried out, e.g., the location of the job in a work group, hierarchical relations, etc.

6. *Job design* is the process of specifying the content of a job in terms of the definition of a job. The design of a job involves the specification of work methods, organizational, and personal contents.

Two major criteria were chosen for analyzing the effectiveness of the job design modifications: quantity of production per man-hour, and quality of work. In addition, some measures of attitude and satisfaction were also used.

The experimental setting was a manufacturing department of a West Coast company which was unionized. The department was devoted to the manufacture of a line of similar products and had been the subject of careful and detailed engineering study over the years. The activities of the department were organized according to the latest manufacturing engineering practices. At the start of the experiment, the product was made on an assembly line, using carefully specified, minutely subdivided operations at which twenty-nine of the department's thirty-five members worked. The rest of the people were concerned with preparing and removing material for the line, inspection and supply. The department was under a manager and two supervisors. A similar department in the company was used as a control group to permit monitoring of the presence of plant-wide changes which might affect employee attitudes, practices and performance.

The investigation centered around the jobs on the assembly line, and modifications were introduced through the department manager. The assembly line workers were unskilled women having an average of four and a half years' experience on the line, ranging approximately from one to seven years. The work content of the original jobs (called Line Job Design) involved performing one of the nine operations, spaced at stations along the conveyor line, required to assemble a hospital appliance. Inspection, in the form of rejecting defective parts going into the assembly, was part of each operation. Job rotation from hard to easy stations and vice versa took place every two hours. The operations were similar in skill requirements and technological content. Pacing eliminated responsibility for productivity, and job rotation with the grouping of work stations for identical operations practically eliminated individual responsibility for quality of work performed.

The experiment was divided into four phases as indicated in Table 1.

#### *Results*

To provide anonymity for company production records, indexes are used. The average hourly conveyor line rate obtained over a period of the consecutive days and divided by the number of persons working on the line is taken as a productivity index of 100. Because individual data are unavailable except for individual job designs, a daily productivity index is used which is the average of individual indexes. The changes in productivity can be seen in Figures 1 and 2. In the Group Job Design which eliminates conveyor pacing, productivity falls markedly

TABLE 1

*Experimental Conditions*

| | Purpose | Criteria | Locations | Workers | Total Number of Days | Number Days Worker Assigned | Production Method |
|---|---|---|---|---|---|---|---|
| A. Line Job Design | Obtain reference base of job design where separate tasks performed on rotated basis by workers | Quantity, quality, some measures of attitude and satisfaction | Main department | 29 | 26 | 26 | Workers rotate among nine stations on belt conveyor, performing minute specified operations at pace of conveyor |
| B. Group Job Design | Eliminate conveyor pacing effects; other conditions primarily the same | Quantity, quality | Adjacent room | 29 | 14 | 2 | Workers rotate among nine individual stations using batch method |
| C. Individual Job Design #1 | Give workers experience on experimental job design where assembly tasks are performed by worker | Quantity, quality | Adjacent room | 29 | 16 | 2 | Workers perform all nine operations at own stations, plus inspection and getting own supplies |
| D. Individual Job Design #2 | Obtain measure on experimental job design | Quantity, quality, some measures of attitude and satisfaction | Main department | 21 | 27 | 6 | Same as C above |

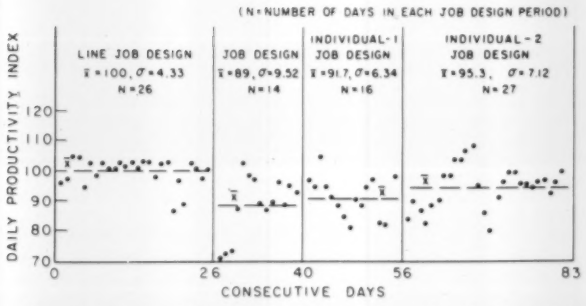


FIG. 1. Average Daily Productivity Indexes for the Four Job Designs (From A. R. N. Marks, "An Investigation of Modifications of Job Design in an Industrial Situation and Their Effects on Some Measures Of Economic Productivity", Ph.D. Dissertation, unpublished, University of California, Berkeley, Nov. 1954, p. 82).

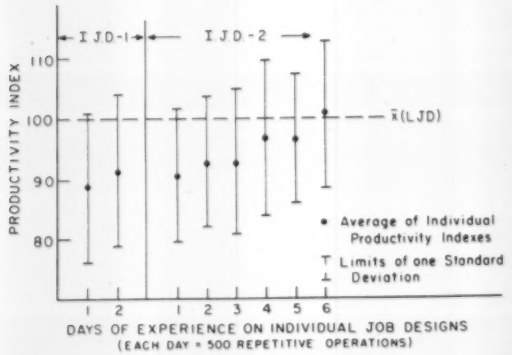


FIG. 2. Average Individual Productivity Indexes (From A. R. N. Marks, p. 83).

below the Line Job Design, indicating the influence of conveyor pacing on maintaining output. Introduction of the Individual Job Design in which workers performed all the operations, controlled the sequence of assembly, secured materials and inspected their own work brought about increases in productivity above the Group Job Design. It should be noted that after six days on the Individual Job Design, the average productivity of the work group exceeded the Line average on which workers had an average of four and a half years of experience.

Measures of quality are based upon results of sampling inspection for attributes both before and after sterilization of the product, and upon the number of kinked assemblies produced. The latter provided a positive direct measure of quality of workmanship since the quality of parts and sub-assemblies were not involved. The changes in quality are given in Tables 2 and 3, and in Figure 3. It is to be noted that beginning with a high level of quality, quality levels rose with the removal of conveyor pacing. When responsibility for quality was placed in the hands of the workers, quality levels rose still higher, for kinked assemblies dropped to one fourth of the original value.

## *Conclusions*

The Individual Job Design:

1. Brought about an improvement in quality, although quality levels were very high originally.
2. Increased the flexibility of the production process.
3. Permitted identification of individuals having deficiencies in productivity and quality.
4. Reduced service functions of the department, e.g., material delivery, inspection.

TABLE 2

*Composite Quality Indexes (AQL Weighted Defects) for the Four Job Designs*

| Inspection | Statistic | Line Job Design | Group Job Design | Individual Job Design—1 | Individual Job Design—2 |
|---|---|---|---|---|---|
| Before sterilization | $\bar{X}$ | 4.17 | 3.52 | 2.14 | 1.55 |
| | $\sigma$ | 3.91 | 4.40 | 2.63 | 2.22 |
| | $N$ = Lots | 60 | 16 | 14 | 26 |
| After sterilization | $\bar{X}$ | 2.42 | 3.11 | 2.27 | 1.35 |
| | $\sigma$ | 3.23 | 4.63 | 2.39 | 1.45 |
| | $N$ | 60 | 10 | 8 | 13 |

TABLE 3

*Summarized Data of Sampling Inspection on the Four Job Designs*

$p$ = estimated process average (fraction defective in per cent)
$R$ = probability of lot being rejected $\times 10^4$
$R_{aql}$ = $R$ for process average equal to $AQL$ value

| Inspection | Type of Defect | AQL Value | Measure | Line Job Design | Group Job Design | Individual Job Design—1 | Individual Job Design—2 |
|---|---|---|---|---|---|---|---|
| Before sterilization | Major | 0.65 | $p$ | 0.173 | 0.262 | 0.087 | 0.090 |
| | | | $R$ | 0.10 | 7.80 | 0.00 | 0.00 |
| | | | $R_{aql}$ | 167.6 | 174.9 | 148.2 | 148.2 |
| | Minor A | 2.5 | $p$ | 0.626 | 0.393 | 0.304 | 0.231 |
| | | | $R$ | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | $R_{aql}$ | 128.0 | 148.1 | 102.6 | 102.6 |
| | Minor B | 6.5 | $p$ | 0.609 | 0.044 | 0.435 | 0.051 |
| | | | $R$ | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | $R_{aql}$ | 82.2 | 113.6 | 22.3 | 22.3 |
| After sterilization | Major | 0.65 | $p$ | 0.124 | 0.061 | 0.048 | 0.026 |
| | | | $R$ | 0.10 | 0.00 | 0.00 | 0.00 |
| | | | $R_{aql}$ | 167.6 | 174.9 | 148.2 | 148.2 |
| | Minor A | 2.5 | $p$ | 0.224 | 0.121 | 0.191 | 0.103 |
| | | | $R$ | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | $R_{aql}$ | 128.0 | 148.1 | 102.6 | 102.6 |
| | Minor B | 6.5 | $p$ | 0.704 | 1.090 | 0.905 | 0.077 |
| | | | $R$ | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | $R_{aql}$ | 82.2 | 113.6 | 22.3 | 22.3 |

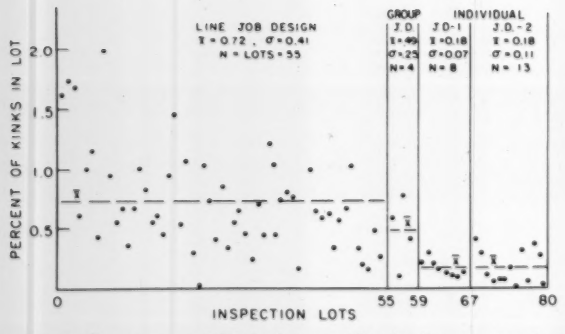


FIG. 3. Percentage of Kinked Assemblies in Consecutive Lots for Four Job Designs (From A. R. N. Marks, p. 87).

5. Developed a more favorable attitude toward individual responsibility, individual work rate, effort expenditure, distribution of work load, and making whole units as compared with *lack* of personal responsibility on conveyor line-type work. After experience with the Individual Job Design, workers disliked the lack of personal responsibility characteristic of the Line Job Design.

## Research Results—Rice

The third piece of research indicates the importance of productivity of the organizational component of job design. A study conducted in an Indian textile mill (18) indicates the impact of job designs which center only about worker-machine allocations and inhibit interaction of workers. The mill had recently been intensively studied by engineers for the purpose of laying out equipment and assigning work loads based on careful work studies of all the job components. After the installation, the mill still failed to produce at satisfactory productivity levels. The job designs provided can be seen by reviewing the assignments of workers in one room containing two hundred and forty looms. Twelve specialist activities were used to run the equipment as follows:

1. A weaver tended approximately thirty looms.
2. A "battery filler" served about fifty looms.
3. A "smash-hand" tended about seventy looms.
4. A "gater," "cloth carrier," "jobber," and "assistant jobber" were each assigned to 112 looms.
5. A "bobbin carrier," "feeler-motion fitter," oiler, sweeper and "humidification-fitter" were each assigned to 224 looms.

The occupational tasks were all highly inter-dependent, and the utmost coordination was required to maintain continuity of production. However, the worker-machine assignments and consequent organizational grouping produced an interaction pattern which mitigated continuity of production. The interaction resulting from work assignment brought each weaver into contact with five-eighths of a "battery filler," three-eighths of a "smash-hand," one-quarter of a "gater" and one-eighth of a "bobbin carrier."

After study of travel patterns and communication patterns, job designs were reorganized so that all of the workers who were inter-dependent were made part of the same work group. Work groups were organized so that a single group was responsible for the operation and maintenance of a specific bank of looms. The geographic division rather than functional division of the weaving room produced interaction patterns which made for regularity of relationships among individuals whose jobs were interrelated and could be held responsible for their production. The results of these changes brought about the following changes in efficiency and damage. Efficiency rose from an average of eighty percent to an average of ninety-five percent after sixty working days. For the part of the weaving shed that was not reorganized efficiency dropped to seventy and finally rose to eighty percent. The mean percent of damage dropped from thirty-two percent to twenty percent after sixty days. Where the job design changes

were not installed, damage continued at thirty-two percent.

The studies presented here are intended to indicate the multi-dimensionality of the job design problem and the pervasiveness of its influence on quantity and quality of output, job satisfaction, etc.

**Future Needs**

By relying on very narrow criteria, jobs have been designed which have a host of disturbing secondary effects in terms of dissatisfaction, monotony, resistance and obstruction. In addition, designs of jobs have frequently failed to yield predicted results. Such failures to achieve anticipated results frequently have been laid to the "contrariness of human nature." This may be taken as another way of stating that, given the current state of knowledge, the effects of job designs cannot be estimated. In view of the engineering, economic, psychological and social consequences of job designs, the inability to predict effectiveness of a particular design indicates two fundamental needs:

1. What factors should guide the design of jobs?
2. What criteria should be used to evaluate the effectiveness of job designs?

Where the content of jobs has been manipulated or redesigned, within a given state of technology, in the direction of enlarging job size or responsibility, gains in productivity and morale as well as reduced costs have been reported. These results serve to illustrate the inability, from the standpoint of the classical method of job fractionation, to predict the consequences of job designs. It is hypothesized that many current personal and productivity problems in industry stem directly from existing job designs.

Some fundamental questions must be raised concerning the design of jobs and the effectiveness of performance on jobs of given design. It is difficult if not impossible at present to provide definitive answers for these. The questions can be divided into three groups, as follows:

1. What influence does job design have on effectiveness of an individual's performance as measured by productivity, quality, long-term costs, satisfaction, morale, etc.?
2. What are the most effective methods of achieving optimum performance? This requires a consideration of the methods of design and specification of jobs, as compared with the methods of palliating the effects of given designs by various means internal and external to the content of one job itself. The effectiveness of job design methods must be compared with the alteration of factors external to the physical job, such as human relations programs, supervision and leadership, incentives, etc.
3. Can a theory of job design be developed and, if so, can it be expressed in the form of guides and principles that can be used by engineers, personnel people, supervisors and managers? Satisfying this need will require a comprehensive research program, concerned with:
   a. The nature of job content as related to job performance, to aspiration, to perception of the individual's role in the organization.
   b. The interrelationships between the technical, organizational and personal requirements of each job.
   c. An evaluation of organization design theories and methods as related to technical and personal requirements for effective performance on jobs.
   d. An evaluation of technical production theories and methods as related to organizational and personal requirements for effective performance on jobs.
   e. An evaluation of the effectiveness of manipulating factors internal and external to job content and the boundary limitations of each.

A good many of the difficulties, the inconsistencies of results, and the opinions held concerning the design of jobs can be traced to the lack of fundamental or true criteria. Before much progress can be made beyond the current status, adequate criteria and sub-criteria will need to be developed. The lack of criteria has led to job designs based upon the satisfaction of apparent economic criteria. The term 'apparent' is used because total costs are seldom considered, for there is little data available to provide yardsticks for total cost analysis of a given job design.

Needed is the development of a total economic cost criterion which is concerned with the total cost of achieving productivity, and therefore includes relevant long-term charges in the form of money, time, growth, and psychological, social and cultural stress costs. One of the serious research problems here is to determine how total economic cost is to be measured in terms of economic, engineering, organizational, social, psychological, physiological, material and human resource cost criteria.

The nature of job design research and experimentation should reflect the multi-dimensional character of the problem. The problem area is amenable to attack from many quarters, under certain requirements. Paramount among the requirements is that job content must be a central theme of all experimentation, with other variables included in various experimental designs. In addition, multi-dimensionality and interaction among variables calls for a problem-centered, research-team approach. Some of the dangers and defects of a compartmentalized approach have been indicated previously.

The types of data that will be required will call for research and field studies that may need to be conducted by industrial engineers, industrial psychologists, sociologists, anthropologists, economists, and researchers in personnel administration and industrial relations. Obtaining the data needed will require that studies be conducted that will range from determining and measuring "meaningfulness" as applied to operations, work methods, work groups and jobs, through the determination of long term total economic cost criteria, to the determination of the means of designing processes, systems, methods and product components in terms of job needs.

Industry's need to be involved in the development of effective job designs is acute at present and will continue to be so as our economy moves into the era of automation. Where automation is not applicable, determining optimum

job designs will be one of the major needs to be met by industry and business in order to maintain, and meet competitively, increasing levels of productivity. In addition effective introduction and use of automation places a very strong demand on job design, theory and principles. These will be needed to help ascertain what processes should be automated with reference to what workers can and cannot do better. They will also aid in the effective design of automation systems regarding the human links, particularly where essential data for making judgments cannot be furnished.

The payoff value that may be estimated for job design research will be extensive for the management sciences, engineering sciences, and social sciences. Concerning management, the availability of job design theories will have a strong bearing on organizational theories and organizational designs, on the design of reward systems, on the design of control systems, communication systems and the operation of a large part of the personnel administration function. In terms of engineering science, the availability of job design theories will have a strong bearing on the development of theories and methods for the design of product, process, equipment, plant conditions, control systems, operations, methods, jobs, etc. Concerning the social sciences in the industrial setting, the availability of job design theories will have a strong bearing upon the formulation of human relations programs and methods, and employee relations programs and methods, organizational methods, supervisory methods (embracing leadership methods), selection and placement of personnel, design of communication networks and reward systems, etc.

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# Topics on the MAPI Formula*

**By Roger Bertrand Orensteen**

*Operations Research, International Business Machines Corporation*

This paper results from the writer's participation in a graduate seminar in capital equipment and replacement policy at Illinois Institute of Technology. The interests of graduate students of equipment policy appear to differ in certain respects from the undergraduates'. First, as a group the graduate students are more interested in the theoretical formulations than is typical of the undergraduate. Second, they have a greater interest in questioning and appraising methods of approach than just learning the techniques of application. To satisfy these interests from the currently available publications in the field of equipment policy was difficult and not entirely satisfactory.

From the questions asked in the seminar, and the discussions that followed, it was clear that only a few of the students had learned from reading *Dynamic Equipment Policy* (1) alone the basic and essential framework of replacement theory upon which the MAPI Formula is based. Judging from these discussions and the writer's own experiences, the major difficulty seems to have arisen in the vocabulary peculiar to the MAPI approach. After a great deal of controversy on a point, it would become clear to almost all concerned that the difficulties were primarily semantic. This was not due to weakness on the part of the students in learning the special terms and their meanings. There just seems to be nothing inherent in the terminology that necessitates proper usage.

There was another factor which did not facilitate understanding the theory behind the MAPI Formula. There was not a direct bridge in the beginning of *Dynamic Equipment Policy* between what the student had already learned and the new MAPI material that was being presented. This is not to derogate from the book. It was not written with our specific and perhaps narrow needs in mind. But new concepts, definitions, etc., are often difficult to handle unless related to something in the prior experience of the student. It would be worthwhile, in the writer's opinion, to approach the MAPI Formula through the Orthodox Minimum Cost Formula directly, rather than as an afterthought for purposes of critical appraisal.

At first it may seem quite out-of-place to think in terms of a MAPI equivalent to the Orthodox Minimum Cost Formula in light of the sharp criticism heaped on this approach in *Dynamic Equipment Policy*. Nevertheless, the MAPI Formula does have its minimum cost counterpart, can be fitted into a minimum cost framework with ease, and is an approach which is generally known and accepted by students of equipment policy. In order to retain the distinction of being new, different, and improved over the Orthodox Minimum Cost formula, it was useful and perhaps necessary to develop a nomenclature peculiar to the MAPI Formula. But for achieving an understanding of the underlying reasoning of the MAPI approach, these new terms seem to present a barrier. So from a teaching standpoint it is thought that considerable support could be offered for a MAPI Minimum Cost Formula, something more closely related to the prior experience of the student and which does not require new terminology.

No attempt will be made in this paper to completely correct the deficiencies cited. Such an undertaking would be beyond the limitations set for this paper. However, from notes made during the seminar, a brief presentation is made of some first thinking on a general approach which might be taken to present a theoretical framework. This approach builds on some rather basic and essential elements which, to one already versed in *Dynamic Equipment Policy*, may seem trivial and elementary. But a symbolism and a series of graphs is developed which, it is hoped, can serve as a common starting point in discussions to avoid getting all tangled up in words. The analytic framework makes up Part I of this paper.

In Part II various questions and points-of-view are presented which were rather controversial in the seminar. Some of these questions are answered with the basic tools presented in Part I. Other questions are answered in terms of some other frame-of-reference. Also some points-of-view presented remain unanswered in this paper. This paper may serve no other purpose than to indicate the kind of thinking, questions, and approach taken by graduate students of equipment policy. On the other hand, it is hoped that a foundation is being made for a broader undertaking of this kind.

Our discussion of the MAPI Formula must wait on some preliminaries. Before proceeding to this objective, it will be necessary to establish some basic concepts on the subject of deterioration and obsolescence. It is to this task that we first turn in Part I.

## PART I

### Operating Costs

The costs of equipment can be categorized in innumerable ways. For our purposes, two general categories will

* Prize-winning graduate essay submitted for the 1954-55 National Awards in Dynamic Equipment Policy sponsored by the National Center of Education and Research in Dynamic Equipment Policy, Illinois Institute of Technology.

be considered: acquisition costs and operating costs. The acquisition costs are usually *lump-sum* costs incident at the time of purchase. The operating costs are incurred at points in the life of the equipment. Other distinctions could undoubtedly be drawn. The important one for our purpose is the time-pattern of the costs, lump-sum versus series. For example, acquisition cost may be, in fact, a series of payments through rental or leasing. Moreover, operating cost may be a lump-sum as a consequence of procuring a contract for the maintenance and servicing of the equipment. Thus, we must think in terms of the true time-pattern nature of the costs rather than their titles.

In both the theory and practice of replacement, operating costs are extremely important. Acquisition costs are present transactions, whereas the operating costs are a problem of the future. In addition, accounting systems generally provide for recording acquisition costs identifiable with the items purchased. Yet it is not often that records of operating costs of particular equipment are kept; and often where such records are maintained, they seldom reveal reliable information useful in equipment analysis. This is indeed unfortunate because the nature of operating costs so often motivates equipment analysis and replacement.

In spite of the lack of empirical data on operating costs, we can make some useful assumptions about them for theoretical purposes. First, we assume they are increasing over the life of the equipment. Second, we assume there are "operating" costs which may be incurred even when the equipment is "not-operating." Certain maintenance costs may fall into this category. Or it is sufficient that the cost pattern just behaves *as if* there were such fixed costs. Figure 1 illustrates some operating cost patterns which are consistent with these assumptions.[1] All of the operating cost curves have been drawn with a fixed portion *OF*. In any particular case the fixed portion may be zero. Or, as already stated, the cost pattern may just behave as if there were such a fixed portion. And although we have for illustration used the same *OF* for all the curves, each curve would have its own fixed portion together with a characteristic time-pattern. With reference to time-pattern, A represents a higher rate of increase in the early life of the equipment than later. *B* represents a constant rate of increase throughout the life of the equipment. *C* represents a lower rate of increase in the early life of the equipment than later.

Of course we could assume any number of different time-patterns for operating costs. Lack of empirical assistance in this regard dictates we make our choice for theoretical purposes on the basis of intuitive reasonableness and analytic expediency. The straight-line, *B*, seems to best fulfill these requirements.

[1] For use in the usual interest formulas, costs are assumed to occur at end-of-period, and although they most certainly are discrete amounts, we draw a smooth curve for illustrative purposes.

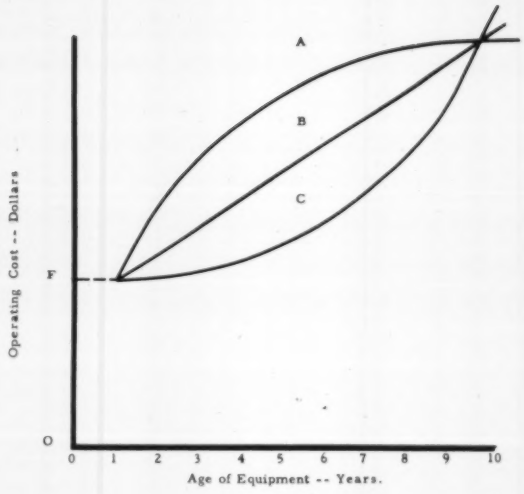


FIG. 1. Operating Costs

### *Deterioration*

The increasing nature of operating costs is popularly described by the word "deterioration." We will define it more exactly and approach this concept through the new replica. In Figure 2 we draw the straight-line operating cost curve of a machine in accordance with our previous discussion. The first year operating cost of a new replica, the identical machine brand-new, is always *OF*. The excess of total operating costs in any particular year over that of a new replica that same year is the deterioration. This is further illustrated by reference to Figure 3.

In Figure 3 we show the operating cost curve of a new machine purchased today, $M_1$; the operating cost curve of a new replica of $M_1$, one year hence, is $M_2$, two years hence $M_3$, etc. The costs themselves would, by the new replica assumption, remain unchanged. However, they always begin at a point in time when the machine is new. The cost curves of an annual series of new replicas can be represented by parallel shifts to the right (or downward if you desire) of the operating cost curves.

Our task is to measure the deterioration of $M_1$ every year throughout its life. Remembering our definition, the deterioration of $M_1$ the second year will be $d$, the second year difference between $M_1$ and $M_2$ (the then new replica). The deterioration of $M_1$ the third year will be $2d$, the third year difference between $M_1$ and $M_3$ (the then new replica). Deterioration is always to be measured in relation to a then new replica. However, to simplify the diagram for later discussion, it will be convenient to construct a horizontal reference line $L$ as shown in Figure 3. The amount of deterioration in a particular year can be measured by the vertical distance between the line $L$ and the $M_1$ line. Take notice that it is not the total operating cost to which we refer by deterioration, but the annual increment.

Once again we refer to Figure 3. From the point-of-view of operating costs alone, a new replica is always superior to its aged counterpart. This naturally follows from the increasing nature of these costs. If two years hence we purchase the then new replica $M_2$, every year thereafter $M_2$ will show lower operating costs than $M_1$ by the amount $d$. The amount $d$ is the inferiority of $M_1$ to $M_2$. By the same reasoning $M_2$ will be inferior to $M_3$ by the same amount $d$. Furthermore, additively, $M_1$ will be inferior to $M_3$ by $2d$, inferior to $M_4$ by $3d$, etc. The initial machine of the series, $M_1$, becomes more and more inferior as time passes, in relation to the conceivably always available alternative, the then new replica. This is inferiority due to age—deterioration. There is another inferiority which must be discussed to complete our preliminaries, obsolescence.

### *Obsolescence*

Generally speaking, we think of obsolescence as the inferiority of a machine to another machine which can perform the same function more economically. The general concept of obsolescence so stated would include our concept of deterioration, for have we not in fact described the new replica? As pointed out above, a machine is always inferior to its new replicas by increasing amounts as time passes. Consequently, it is desirable to consider obsolescence as the inferiority of a *new replica* of a machine to another machine which can perform the same function more economically.

There are a number of factors that can enter into the inferiority of a new replica. It may result from a change in consumer tastes which through the dynamic forces of the market render the existing machine less desirable. Technological change could permit the performance of the same function with lower operating costs, or a lower acquisition cost, or a new combination of higher or lower acquisition costs and operating costs such that on net balance there is overall economy. In practice an actual replacement by reason of obsolescence may be the result of many such forces as mentioned, opposing or supporting one another such that replacement is indicated. For the purposes of theoretical replacement, however, we must make simplifications. We shall concentrate our attention on one class of such influences—technological improvements in the machines themselves. And we will define technological improvement to mean something very specific.

In Figure 4 we reproduce the operating cost curves $M_1$ and $M_2$ and the reference line L with the same meaning as given to them previously. Let us assume that one year hence there will be a machine available capable of performing the same function as $M_1$, but superior to the one year old $M_1$. Such a machine could by this description be a new replica. But in this case we wish to describe obsolescence, so our new machine superior to $M_1$ must be superior to the new replica itself. What does this mean graphically?

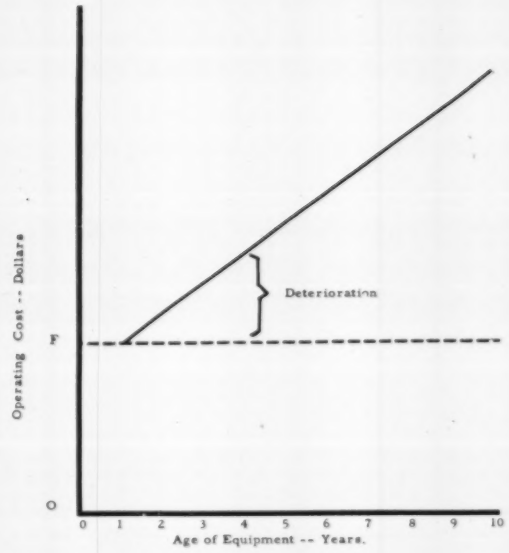


FIG. 2. Operating Costs

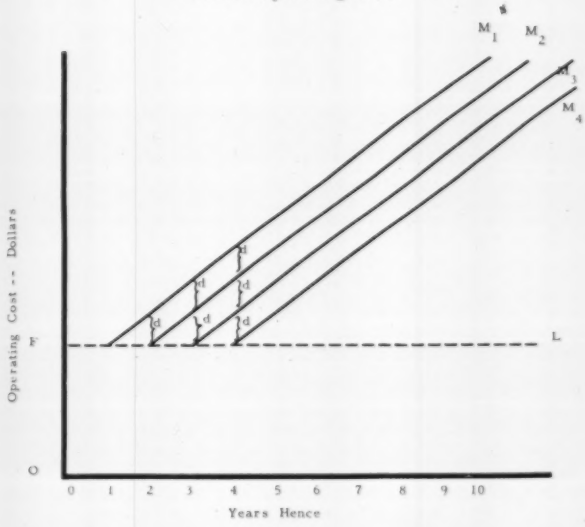


FIG. 3. Operating Cost for New Replicas

By "superior to the new replica" we mean something very definite—lower operating costs by reason of a lower and parallel shift in the operating cost curve.[2] This is analogous to the shifts in operating cost curves by reason of deterioration. However, in this case, the fall in the operating cost curve must be greater than that of the new replica in order for the improved machine to be superior to the new replica. The operating cost curve of the new

[2] *Dynamic Equipment Policy* is not very specific on this point. Nothing more is mentioned except that operating costs are lower. However, an operating cost curve can be lower than another without being parallel. And, an operating cost curve can be partly lower than another and partly higher, yet have a lower operating cost present worth.

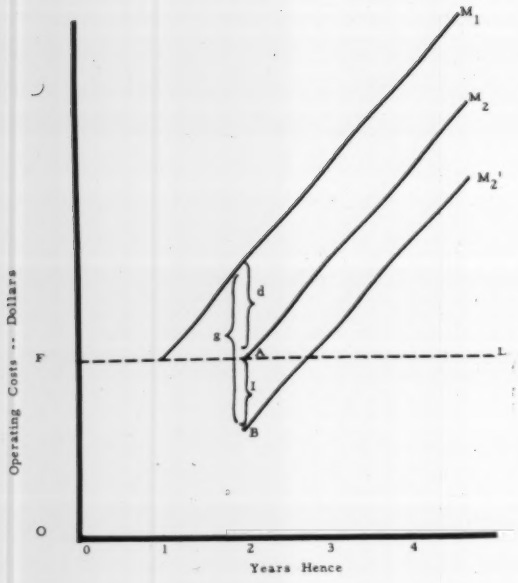


FIG. 4. Operating Costs for Improved Machine

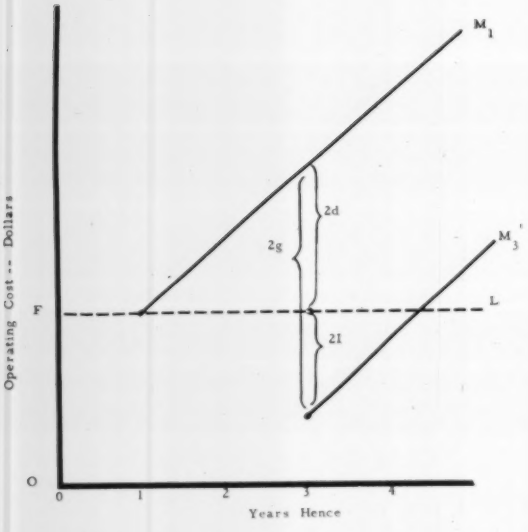


FIG. 5. Operating Cost for Improved Machine

replica one year hence would be $M_2$, drawn through the point A and parallel to $M_1$. Thus, for an improved machine to be superior to a new replica $M_2$ and exhibit the desired curve shift, the cost curve of the improved machine must go through a point lower than A, say, B, and likewise be parallel to $M_1$. We will identify improved machines by primes on the symbol for the then new replica to which they are superior. The improved machine to $M_2$ is thereby designated $M_2'$.

The amount by which a new replica is inferior to the improved machine $M_2'$ is the vertical distance AB which we will hereafter denote by $I$. The amount by which $M_1$ was inferior to its new replica $M_2$ is, as before, $d$. Thus, the total amount of inferiority of $M_1$, in relation to the then available improved machine $M_2'$, is $d$ plus $I$. We will represent this sum by the symbol $g$.

In Figure 5 we redraw Figure 4 omitting the curve $M_2$ for the new replica, but remembering its position. Moving on to the next year, year three, we once again assume the existence of an improved machine, in this instance, $M_3'$. It is naturally superior to the new replica $M_3$, otherwise it would not be an improved machine by our definition. Very important, we assume it is an improvement over the improved machine of the previous year. Since the improved machine of the year before was superior to a new replica by an amount $I$, we assume that our currently available improved machine is superior to its associated replica $M_3$ by an amount $2I$. Thus, the amount of improvement of the improved machine $M_3'$ over the improved machine of the previous year $M_2'$ is $I$. To illustrate graphically, we draw the operating cost curve $M_3'$ in accordance with our assumptions. $M_3'$ must be $2I$ below the cost curve $M_3$ (which we have omitted). Since $M_3$ would begin at the reference line $L$, we can begin our $M_3'$ curve a distance $2I$ below the reference line. $M_3$ would be $2d$ below $M_1$. Therefore, the total inferiority of $M_1$ to $M_3'$, then available improved alternative, would be $2d$ plus $2I$ or $2g$.

We repeatedly carry out our assumption regarding the improved machine that becomes available each succeeding year. Each succeeding improved machine is better than the one of the previous year by a constant amount $g$. Thus, the total inferiority of the machine $M_1$ to the improved machine rises each year by an amount $g$. Part of this rise is deterioration, the annual increase in operating costs in relation to a new replica. Part of this rise is obsolescence, *the annual increase in operating costs of a new replica* in relation to the improved machines that become available.[3] Translated into less technical language, machine $M_1$ is getting less efficient due to aging and lower operating costs of improved machines.

Inferiority is one thing, operating costs another. First, inferiority is always inferiority to something. If, for example, we refer to the inferiority of the machine $M_1$ to a new replica, we mean only deterioration. If we refer to the inferiority to the improved machines that become available, we mean both obsolescence and deterioration, total inferiority. Second, inferiority is an increment, not a total, an excess of operating cost itself. It is therefore possible to go from inferiority to operating cost in a definite relationship. We illustrate this graphically in Figures 6, 7, and 8.

$X$ is the operating cost curve as we knew it originally, an initial amount $OF$ plus an annual increase $d$; or stated

[3] To this point we have stated the equivalent, a fall in operating cost of the improved machines in relation to the new replica.

equivalently, the operating cost of a new replica that year, $OF$, plus the excess of operating cost for machine $M_1$ over that of a new replica (Figure 6). $Y$ is the operating cost curve as we know it now, an initial amount $OF$ plus an annual increase $g$ ($d$ plus $I$); or stated equivalently, the operating cost of a new replica as before, plus the excess operating cost of the new replica now, plus the excess operating cost of $M_1$ over the operating cost of a new replica now (Figure 7).

There are some important distinctions to draw between $X$ and $Y$ (Figure 8). $X$ is the operating cost curve of $M_1$ when the best alternative is always a new replica. $Y$ is the operating cost curve of $M_1$ when the best alternative is a machine improved over the new replica, in accordance with our assumption. The operating costs of $X$ are anticipated expenditures; the operating costs of $Y$ are the anticipated expenditures of $X$, plus the *anticipated foregone savings in operating costs* made possible by the improved machines. There are savings due to improved alternatives, but foregone savings because of a prior commitment in $M_1$.

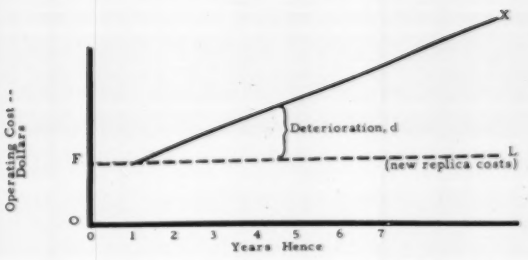


FIG. 6.

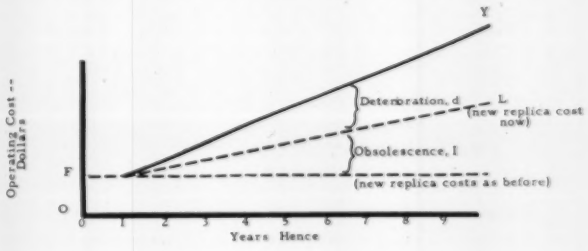


FIG. 7.

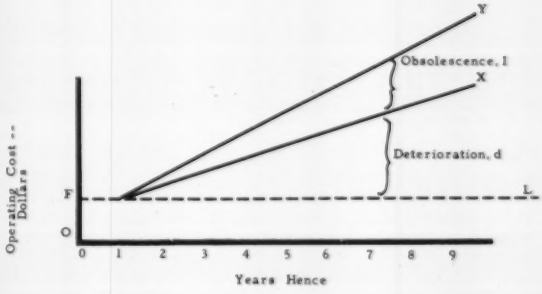


FIG. 8.

### The Minimum Cost Formula

Our interest in minimum costs is so obvious as to hardly need mention. It follows from an overall goal of business enterprise—additions to net profits. An aspect of this goal particularly important in equipment policy is the minimization of costs over time. That is to say, the actual cost of a machine is related to the length of the period it is retained in the use under consideration. This being the case, we would most certainly desire to retain the machine over the optimum period, to that point in time which shows the lowest possible costs.

The uniform annual equivalent acquisition cost is definitely related to the period of retention. The longer the period, the smaller the cost. This is illustrated by Curve $A$ in Figure 9. With regard to operating costs, we have a problem. As we have seen from previous discussion, there are two possible operating cost curves that could be used. One curve represents the operating costs when the best alternatives to the aging machine are assumed to be the new replica. The other curve represents the operating costs when the best alternatives to the aging machine are assumed to be machines successively improved over the new replicas. If we build our minimum cost formula on the basis of the first mentioned operating cost related to new replicas, we will have the *Orthodox Minimum Cost Formula*. If, however, we proceed to build a minimum cost formula based upon the operating costs as related to improved machines, we have the minimum cost equivalent of the MAPI Formula, a *MAPI Minimum Cost Formula*. From the MAPI Minimum Cost Formula the transition to the MAPI Formula itself is simple.

Our total cost is composed of two parts, acquisition cost and operating cost. The uniform annual equivalent acquisition cost declines with the period of retention, as already pointed out. On the other hand, the uniform annual equivalent operating cost will naturally increase with the period of retention. This relationship is shown in Figure 9, Curves A and B. Obviously we cannot attain our goal of minimization by treating these two costs independently. Annual acquisition cost is minimized by retaining the equipment indefinitely; annual operating costs are minimized by retaining the equipment for the shortest possible time. We attempt to minimize the total of both costs to achieve a balance. The total costs for different periods of retention are shown by the U-shaped Curve C in Figure 9.

In order to derive a useful minimum cost formula, we will follow the simplifying procedure of *Dynamic Equip-*

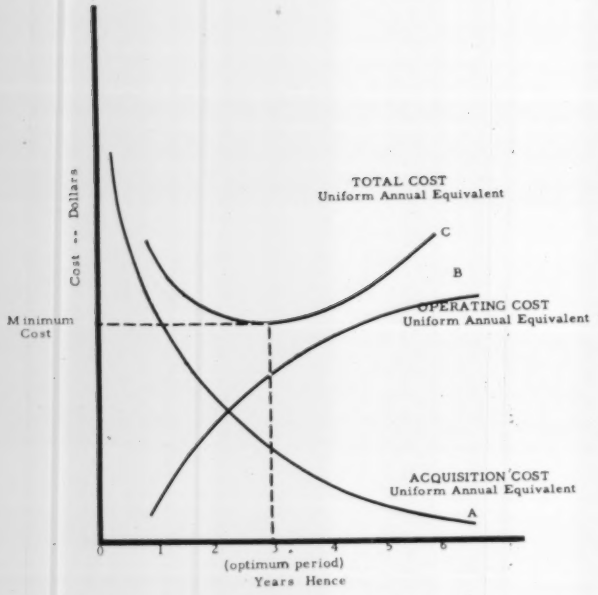


FIG. 9. Costs of a Machine

*ment Policy* (1, p. 94). Although the result is an approximation, it very well suffices for our purposes. In lieu of the uniform annual equivalent of acquisition cost, we take average depreciation plus interest on the average purchase price,[4] as follows:

$$(1) \qquad \frac{c}{n} + \frac{ic}{2}$$

where $c$ = acquisition cost
$n$ = time period, years
$i$ = interest rate, decimals

In lieu of the uniform annual equivalent of operation cost, we take one-half the product of the deterioration times the number of years in the period less one, plus the first year operating cost, as follows:

$$(2) \qquad F + \frac{d(n-1)}{2}$$

where $F$ = first year operating cost
$d$ = annual increment in operating costs, deterioration
$n$ = time period, years

The total cost thus becomes:

$$(3) \qquad \text{Total Cost} = F + \frac{d(n-1)}{2} + \frac{c}{n} + \frac{ic}{2}$$

The total cost is a minimum when the time $n$ is

$$(4) \qquad \sqrt{\frac{2c}{d}}$$

[4] The following discussion is based upon no salvage value. It could just as well be based on the alternative assumption of a salvage case, but this would unduly complicate the discussion here.

Substituting (4) into (3) and simplifying, we determine the annual cost associated with this optimum period of retention:

$$(5) \qquad \text{Orthodox Minimum Cost} = F + \sqrt{2cd} + \frac{ic - d}{2}$$

We have now derived a minimum cost formula for a machine when operating costs are related to new replicas. To derive the minimum cost equivalent of the MAPI Formula, we simply insert $g$ in place of $d$ in the above formula, and the result is

$$(6) \qquad \text{MAPI Minimum Cost} = F + \sqrt{2cg} + \frac{ic - g}{2}$$

Comparing (6) with (5) we observe that the MAPI Minimum Cost is always greater or equal to the Orthodox Minimum Cost because $g \geq d$, other things remaining equal.

## The MAPI Formula

The transition from the MAPI Minimum Cost Formula to the MAPI Formula itself is a simple step. But before taking it, we make some preliminary observations, and important ones in understanding the MAPI approach.

Up to now we could refer to the cost of a single machine in a meaningful way. What we had in fact derived for a machine was the cost of the machine relative to not having any machine at all. However, in the MAPI Formula we change our approach. The costs we compute are the costs of a machine relative to the costs of another machine. Therefore, *the cost of a machine we arrive at through the MAPI Formula has no meaning in its own right*—it is a cost relative to another machine, and we must always know the other machine and its costs too.

Following the principle that in using the MAPI Formula we must always refer to pairs of machines, we set up a MAPI Minimum Cost for each of two machines, say, $C$ and $D$.

$$(7) \qquad \text{MAPI Minimum Cost Machine } C = F_c + \sqrt{2c_c g_c} + \frac{ic_c - g_c}{2}$$

$$(8) \qquad \text{MAPI Minimum Cost Machine } D = F_D + \sqrt{2c_D g_D} + \frac{ic_D - g_D}{2}$$

Now we are ready to take the final step into the MAPI Formula. We observe the following:

$$(9) \qquad \text{MAPI Minimum Cost Machine } C \lessgtr \text{MAPI Minimum Cost Machine } D$$

This relationship between machines $C$ and $D$ is not disturbed if the same amount is subtracted from both sides of this inequality (or equality). If $F_D$ is greater than $F_C$ the most convenient subtraction is $F_C$. We will subtract $F_C$ from both the MAPI Minimum Cost of $C$ and $D$. Our

expression for the cost of machine $C$ becomes:

$$\sqrt{2c_c g_c} + \frac{ic_c - g_c}{2} \tag{10}$$

Our expression for the cost of machine $D$ becomes:

$$(F_D - F_C) + \sqrt{2c_D g_D} + \frac{ic_D - g_D}{2} \tag{11}$$

In the MAPI Formula we give this resulting expression a name of its own—adverse minimum. We have the adverse minimum of machines $C$ and $D$. In addition, we give the expression $(F_D - F_C)$ a special name—next year operating inferiority of machine $D$ to machine $C$. As before $g_C$ is the operating inferiority of machine $C$ to the best available alternatives in the future which are improved machines in accordance with our assumption.

We will not delve further into the theory of replacement. The reader is referred to *Dynamic Equipment Policy* for the balance. We now have the essential and basic tools of analysis for the discussion to follow.

## PART II

### The Standard Assumptions

*Introduction*

Perhaps no other aspect of the MAPI Formula has caused so much confusion and criticism as the standard assumptions (1, Ch. 5). The confusion seems to be primarily a consequence of the vocabulary of *Dynamic Equipment Policy*. The criticism, on the other hand, generally stems from attempts to test the empirical validity of the assumptions with the view towards proving the MAPI Formula to be unrealistic and therefore useless. In the discussion that follows we will first with the aid of the tools provided by our previous discussion, attempt to clarify the areas of confusion. Then we can concentrate on the important question of the empirical validity of the assumptions.

*Confusion*

There is quite a diversity of confusion surrounding the two standard assumptions (1, p. 73). There is the student who claims they are tautologies. At the other extreme there is the charge that they are contradictory. The tautology reasoning is involved and somewhat difficult to trace. But the contradictory charge is easy to see. The first assumption states that each future challenger is better than the preceding one by a constant amount. The second standard assumption seems to contradict this by making all future challengers equivalent to the present challenger through identical adverse minimums.

Let us refer to formulas (10) and (11) for assistance. From formula (10) it can be seen that for a series of challenging machines to have the same adverse minimum, they must all have identical $g$'s and $c$'s, or a combination of different $g$'s and $c$'s such that the resulting adverse minimums are the same. However, it is easy to see that all future challengers have the same $g$ as the present challenger. The $g$ is the amount of improvement of each succeeding challenger over the preceding one. The following is a table of total operating inferiorities for a series of challengers:

| *Challengers* | *Total Operating Inferiorities* |
|---|---|
| $M_1$ | 0 |
| $M_2'$ | $g$ |
| $M_3'$ | $2g$ |
| $M_4'$ | $3g$ |
| ⋮ | ⋮ |
| $M_{n-1}'$ | $(n-2)g$ |
| $M_n'$ | $(n-1)g$ |

Our first standard assumption fixes the relationship between all future challengers, $M_2'$ through $M_n'$, to the present challenger $M_1$. If we attempt to derive an adverse minimum of some future challenger, say, $M_2'$ we consider a series of challengers headed by $M_2'$. The amount of improvement of succeeding machines over the previous ones, in the series headed by $M_2'$, is obviously the same as before, $g$ ($3_g - 2_g$, $4_g - 3_g$, etc.). And no matter what machine of the series headed by $M_1$ we choose for determining an adverse minimum, the answer would naturally be the same. They all have the same $g$ to be used in formula (10).

In formula (10) we have determined $g$ for all future challengers to be the same as that of the present challenge, $g$. The interest rate is to be assumed the same for all future challengers. There remains the adverse minimum and the acquisition cost. Terborgh chooses to fix the adverse minimum by his second standard assumption. Since he assumes that the adverse minimum of all future challengers is identical with that of the present challenger, it follows that they must likewise have identical acquisition costs.

We are now prepared to answer the question of tautology. The two standard assumptions would be tautological had the acquisition costs been fixed by assumption. Without either an assumption regarding acquisition costs or adverse minimums, the presentation would be incomplete. With this in mind, Terborgh obviously prefers to fix the adverse minimums, thereby also fixing the acquisition costs.

To discuss the charge of contradiction in the standard assumption, we refer again to formulas (10) and (11). Let us picture ourselves standing, for example, in year four. There are three machines to consider: (1) four year old $M_1$; (2) new replica of $M_1$, $M_4$; and (3) improved machine $M_4'$. The new replica $M_4$ has the same adverse minimum as a new $M_1$. The improved machine $M_4'$ has the same adverse minimum, by the second standard assumption, as the new $M_1$. Therefore $M_4$ and $M_4'$ have the same adverse minimums in year four. It seems at first glance, we should be indifferent as regards $M_4$ and $M_4'$ in year four. Is this a contradiction of our assumption that $M_4'$ is an improvement over $M_4$?

The key in our discussion here is that in working with the MAPI Formula, we must constantly remember that *an adverse minimum has no meaning in its own right.* It is one

of a pair of costs which have no separate meaning. The only time it is proper to directly compare the adverse minimums of $M_4$ and $M_4'$ is when these machines are paired in making the cost calculation. This has not been the case. The pairs to which we refer are as follows:

$M_1$ and $M_4'$

$M_1$ and $M_4$

Let us proceed to make our comparison properly. The new replica $M_4$ has the adverse minimum, identified by the symbol $AM(M_4)$,

$$AM(M_4) = \sqrt{2cg} + \frac{ic - g}{2} \tag{12}$$

The associated adverse minimum for the four year old $M_1$ is

$$AM(M_1) = (F_{M_1} - F_{M_4}) + \sqrt{2cg} + \frac{ic - g}{2} \tag{13}$$

Since $M_1$ is a four year old $M_4$, and $M_4$ is a new replica, the expression in $F$ must equal $3d$. Inserting this amount for the expression in $F$ and comparing (13) with (12) we arrive at the following:

$$AM(M_1) - AM(M_4) = 3d \tag{14}$$

That is to say, $M_1$ is inferior to $M_4$, the new replica, in the amount $3d$.

Let us now compare $M_1$ with the improved machine $M_4'$. The adverse minimum of the improved machine is

$$AM(M_4') = \sqrt{2cg} + \frac{ic - g}{2} \tag{15}$$

The associated adverse minimum of the four year old $M_1$ is

$$AM(M_1) = (F_{M_1} - F_{M_4'}) + \sqrt{2cg} + \frac{ic - g}{2} \tag{16}$$

By the first standard assumption, the expression in $F$ is fixed and equal to $3d$ plus $3I$. Inserting this amount in (16) for the expression in $F$ and comparing (16) and (15) we arrive at the following:

$$AM(M_1) - AM(M_4') = 3d + 3I \tag{17}$$

That is to say, $M_1$ is inferior to $M_4'$, the improved machine, in the amount $3d$ plus $3I$. We have already concluded that $M_1$ is inferior to the new replica $M_4$ by the amount $3d$. Thus, $M_1$ has a greater inferiority to $M_4'$ than to $M_4$. We conclude that *one cannot be indifferent in choice between $M_4$ and $M_4'$ as might be indicated from their equal adverse minimums, formulas (12) and (14)*. Properly paired, the correct relationship between the various machines is evident. This is as it should be and is strictly in accordance with our standard assumptions. The main difficulty seems to arise, practically speaking, because there is nothing inherent in the terminology, adverse minimum, etc. that necessitates proper pairing before comparison. Consequently, there seems to be an apparent but unreal contradiction in the standard assumptions.

It is of interest to see how our approach must be modified if we pair $M_4$ and $M_4'$ directly to avoid the circumlocution of comparing each independently with a common partner, $M_1$. The adverse minimum of $M_4'$ would be

$$AM(M_4') = \sqrt{2cg} + \frac{ic - g}{2} \tag{18}$$

The adverse minimum of the associated machine $M_4$ would be

$$AM(M_4) = (F_{M_4} - F_{M_4'}) + \sqrt{2cg} + \frac{ic - g}{2} \tag{19}$$

We have fixed the expression in $F$ by our standard assumptions. The improved machine is better than its associated replica of $M_1$, $M_4$, by $3I$ in year four. Inserting this amount for the expression in $F$ and comparing (19) and (18) we arrive at the following:

$$AM(M_4) - AM(M_4') = 3I \tag{20}$$

The result in (20) is the same that would have been arrived at by comparing $M_4$ and $M_4'$ through the less direct approach as follows:

$$AM(M_1) - AM(M_4') = 3d + 3I \tag{21}$$

$$AM(M_1) - AM(M_4) = 3d \tag{22}$$

Subtracting (21) from (22) the result is identical with that in (19):

$$AM(M_4) - AM(M_4') = 3I \tag{23}$$

*Criticisms*

Much of the criticism of the MAPI Formula rests on the alleged lack of empirical validity of the standard assumptions. No attempt will be made here to prove or disprove the empirical reasonableness of the assumptions. Indeed, such arguments are completely irrelevant when we try to determine how good is the MAPI Formula itself. To test the formula on the basis of its assumptions is simply to beg the question. An example of such reasoning is as follows:

> The character of the problem, that is, guessing how technical progress will affect the comparative cost behavior of unborn models, has been accurately sized up by George Terborgh. His replacement rule is essentially the average-minimum-cost rule, with a sophisticated method of allowing explicitly for obsolescence. Such a frontal attack makes sense in logic, but it is hard to say that it produces better guesses about the effects of future obsolescence than tinkering with the average-cost curves. Moreover, his simplified versions of the rule may be misleading to the unwary, since the formulas are based on the stiff assumption that operating costs plus obsolescence inferiority increase through time along a straight line (2).

The standard assumptions could conceivably be based upon empirical studies of great magnitude. On the other hand, one might just hazard a guess as a basis for the assumptions. The assumptions are useful abstractions of the real world as we know it, or guess it would be if we did know it more intimately. So you see, there is more involved than just examining the assumptions and discarding the formula if the assumptions appear unreasonable. The test

of the assumptions, if at all required, must be made by other than the subjective and vascillating judgment of the observer. The mere fact that the assumptions may be guessed at is insufficient evidence to discard them.

We apparently have two problems in testing the MAPI Formula: 1. how good are the end-items, the answers; and 2. how good are the assumptions. But really there is only one problem, the first. To answer the first disposes of the second also. The adequacy of the assumptions can be tested only in terms of the results or predictions which the formula affords. If the results are adequate, the assumptions are likewise satisfactory. If the results are inadequate, we must look to the assumptions as a possible weakness.

Our reply to those who challenge the MAPI assumptions is simple and direct. You desire to test the validity of the MAPI Formula by determining the empirical reasonableness of the assumptions? The correct way of determining this reasonableness is by testing the MAPI Formula. Tell me how good are the formula answers. Then I can tell you if the assumptions are adequate, if you still desire this now

## Equivalence of the MAPI Formula to Orthodox Minimum Cost

In this portion of the paper an argument will be presented which is quite contrary to the approach in *Dynamic Equipment Policy*. In this book criticisms have been directed at the orthodox minimum cost formula in support of the MAPI approach (1, pp. 176–186). There are those, however, who believe in the *equivalence* of the MAPI Formula to orthodox methods. In this respect, they say, the MAPI Formula has merit—it is at least as good as its alternatives because it produces equal results. To some, such arguments as these are as much a defense of the MAPI Formula as a criticism, since there must be a few who still revere the long-established orthodox methods in preference to the new. The arguments in favor of equivalence follow.

The minimum cost formula of long tradition is charged with ignoring obsolescence entirely (1, p. 180). It is difficult to envisage how such an obvious economic phenomenon could escape the equipment analyst for so long. And it is doubtful that economic replacement theory is only now discovering that anticipated obsolescence is a cost to consider.

In the MAPI Formula, by way of review, present challengers are evaluated against a succession of future, improved alternatives, in addition to the present defender. Whereas traditional minimum cost formulas supposedly consider only physical aging, deterioration, the MAPI Formula is calculated to include economic aging, obsolescence, as well. In a dynamic economy the kind of replacement caused by deterioration is apt to be far less common than that caused by obsolescence. Several methods of considering obsolescence in the orthodox approach are now to be discussed.

### *Increment in Rate of Return*

The rate of return to be used in an economy study is in general to represent the best earnings of an alternative investment of equivalent risk. The increment in rate of return over that of the implicit or explicit cost of borrowed capital is to compensate for the additional hazards to that of the user of capital over that of the lender. Obsolescence has always been one of these hazards. The greater the risk of obsolescence, the higher the interest rate necessary to compensate for this hazard.

Granted that obsolescence can be considered in this way, as just one of the many risks to be compensated for by a rate of return, the inferiority gradient, $g$, can be described as a *substitute* for the increment in rate of return. Otherwise we would be double-counting. For example, assume a rate of return in the orthodox minimum cost analysis of 15 per cent, of which there is included 7 per cent to compensate for the hazards of obsolescence. If we assume, also, that our equipment will accrue operating inferiority of, say, $40 per year due to obsolescence, and add this amount to the progressive deterioration, etc., it is not proper to use the same interest rate as before. Indeed, we must forget about the 7 per cent, for we have taken care of the hazards of obsolescence in another way. In fact, if the inferiority gradient is to compensate for the same risk as the increment in rate of return previously accounted for, and all other factors are also unchanged, it follows that the net result, the minimum time-adjusted annual average cost must be the same under either method.[5] Moreover, this is the only objective test we have as to whether the inferiority gradient which is substituted for a portion of the rate of return is correct, since they are not all measured in like units and there is an absence of empirical evidence describing obsolescence patterns.

To better explain the inferiority gradient as an equivalent to the rate of return, Table 1 has been prepared from the formula for the no-salvage case (1, p. 95). From this table it is possible to determine the rate of interest (per cent) which will produce the same adverse minimum/acquisition cost ratio with various gradient/cost ratios.

---

[5] In Chapter XI of *Dynamic Equipment Policy*, pp. 176–186, a comparison is made between the "orthodox engineering formula of minimum average cost", and the "gap and gradient basis". Table 9 illustrates that the minimum average cost method produces different results than the Machinery and Allied Products Institute method when, all other things unchanged, the MAPI method assumes $100 a year in obsolescence added to the $100 in operating costs. Here is an example of double-counting. When the $100 a year obsolescence was added into the calculations, the same interest rate was used as in the minimum average cost alternative where obsolescence was not considered as a gradient. Unless we are considering Table 9 as two separate economy studies, in lieu of two solutions to the same problem, the hazard of obsolescence is the same in each case. If we translate this hazard into a gradient, one must remove from the 10 per cent that portion representing a compensation for anticipated obsolescence. In Grant, E. L., *Principles of Engineering Economy*, The Ronald Press Company, New York, 1950, p. 526, the author similarly compares the two methods without considering the effect on the interest rate of the assumed obsolescence gradient.

TABLE 1

*Rate of Interest Necessary to Produce a Given Adverse Minimum/Acquisition Cost for Various Gradient/Acquisition Cost, Assuming No Salvage Value*

| % Adverse Minimum/ Acquisition Cost | % Gradient Cost | | | | |
|---|---|---|---|---|---|
| | 5% | 4% | 3% | 2% | 1% |
| 15 | | | | | 3 |
| 20 | | | | 2 | 13 |
| 25 | | | 6 | 12 | 23 |
| 30 | 2 | 8 | 16 | 22 | 33 |
| 35 | 12 | 18 | 26 | 32 | 43 |
| — | — | — | | | |
| 40 | 22 | 28 | 36 | 42 | 53 |

For example, when the gradient/cost ratio is 4 per cent and the adverse minimum/acquisition cost ratio is 35 per cent, the requirement is for an interest rate of 18 per cent. The identical adverse minimum cost/acquisition cost ratio can be obtained with a 5 per cent gradient/cost ratio and a rate of return of only 12 per cent. Under these conditions we summarize:

| *gradient/cost ratio* | *interest rate* |
|---|---|
| 4% | 18% |
| 5% | 12% |

(adverse minimum/acquisition cost ratio of 35%)

Assume a case where deterioration might take place at an annual rate of 4 per cent of acquisition cost, and an 18% rate of return would be considered appropriate to compensate for all hazards *including obsolescence*. If we desire to increase our gradient from 4 per cent to 5 per cent to take care of obsolescence, we must reduce our rate of interest accordingly, from 18 per cent to 12 per cent. Thus a 6 per cent portion of the 18 per cent return is necessary to compensate for a one-fourth increase in the gradient as an obsolescence allowance in this example.

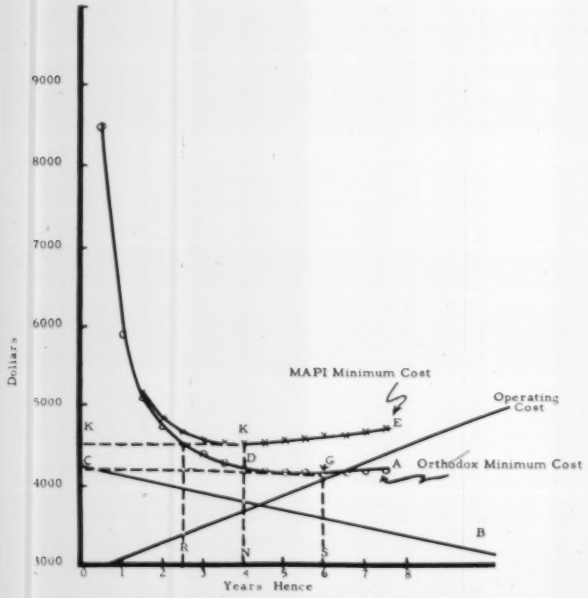


FIG. 10. Service Lives and Capital Recovery Periods

*Service Lives and Capital Recovery Periods*

In addition to the increment in rate of return which is like the inferiority gradient, there are service lives and capital recovery periods to consider. Short time periods against which to allocate costs have always been a device for recognizing great risk, including obsolescence. Indeed, this is recognized by the proponents of the MAPI Formula; but in this instance, unlike the increment in rate of return, they caution against double-counting (3, p. 47):

> As pointed out earlier, full allowance for deterioration and obsolescence is built into our formula and does not need to be made a second time by abridging the life estimate.

Here, in addition, is some evidence that previous methods have not ignored obsolescence altogether (3, p. 47):

> Avoid also the arbitrary shortening of these estimates so often employed under other methods to allow for obsolescence.

We will refer to Figure 10 in our continuing discussion of service lives and capital recovery periods. There are the familiar U-shaped annual cost curves (no-salvage case).[6] Curve $A$ includes only deterioration as a cost, not obsolescence. On this basis the equipment will be replaced by a new replica every $S$ years, at the point where the cost of operating the equipment for another year exceeds the minimum time-adjusted annual average cost for the new replica. The corresponding minimum cost is $C$.

Now assume that after neglecting obsolescence in our original cost calculations, this phenomenon actually materializes, and in a particular time-pattern. The time-pattern suggested by Terborgh is linear and falling; that is, after the acquisition of the equipment, with each passing year comes an improved alternative with its lower operating cost. And the operating costs are assumed to fall by a constant amount each year. Line $B$ depicts this characteristic. Replacement will then be signaled at year $N$ instead of $S$, since it is at this point that the cost of operating for another year exceeds the minimum annual time-adjusted annual average cost of the best available alternative which is now *not* a new replica. The apparent cost is $D$ instead of $C$.

There is a defect in considering $D$ the *real* cost of the equipment replaced. The foregone alternatives up to year $N$ are not included in this amount. In order to calculate the real cost of the equipment it is necessary to add in the difference between the minimum time-adjusted annual average cost of the new replica and the then available improved alternative, for every year up to $N$. Of course this would be time-adjusted with interest formulas.

Now let us begin all over again and anticipate the obsolescence in accordance with line $B$. We recalculate the average time-adjusted annual average cost curve, but with

[6] The data from which the curves are drawn are given in Terborgh, *op. cit.*, p. 181.

anticipated obsolescence as a cost. The minimum point of the new curve $E$ should be at year $N$ where replacement will now be signaled. This is the economic life of the equipment. The real minimum cost will now be at $K$, which is above $D$, the apparent cost for life $N$, and which is above $C$, the cost where obsolescence is not directly included as a cost.

It should be clear that our goal is to arrive at the correct cost. The other information, such as economic life, is supplementary. Under our assumptions, the correct cost is $K$ because it takes into account the foregone alternatives. Notice that this same cost can be reproduced by apparently excluding obsolescence from the calculations and using a capital recovery period of $R$. That is, we back up on Curve $A$ to the cost which is correct. This is an alternative to the method of including obsolescence directly, as a gradient, for it produces the same cost! It is of particular interest to note that the assumed capital recovery period must *necessarily be less than the economic life*. If it were identical with the economic life $N$ our cost would be $D$, understated. Therefore, a capital recovery period less than the economic life can produce equivalent results as when obsolescence is directly included as a gradient. Through this shortened capital recovery period, we are taking into consideration obsolescence—that this period is not the same as the economic life is no test of its correctness.

The important thing is to produce the correct cost. The equipment once acquired will be tested for replacement under the conditions then prevailing. And if we have been farsighted and accurate, in year $N$ replacement will be signaled by calculations made *then*. The fact that we originally used a shorter period $R$ in our calculations is no longer relevant as a factor in subsequent analysis. It is a characteristic of these periods that they necessarily be short in relation to the economic life and this should not be disturbing.

### *Salvage Values*

Another way that obsolescence can be introduced into the economy study is through salvage values. It is often customary and convenient to assume a particular pattern of salvage values over the life of the equipment. This pattern can easily be altered to consider obsolescence—either by a lower and parallel shift of the pattern or a change in the shape of the pattern. For example, one might assume a higher than usual rate of decline in value in the early years of equipment when obsolescence is expected to be high. Certainly the salvage value of equipment is related to the existence of improved alternative equipment.

### *Substitution of Techniques*

Those who believe that the MAPI approach does not represent a basic change in content for economy studies now conclude their case. The MAPI approach, they say, is merely the substitution of one obsolescence technique for another—inferiority gradient for increment in rate of return, salvage values, and capital recovery period. It is conceivable that the analyst might use any of the four approaches exclusively, or in any combination to reflect the hazards of obsolescence. It is only that any combination so chosen must not include double-counting and will be equivalent to all of the others in its effect to produce the same cost. They all must compensate for the same degree of risk for the given situation. And in the absence of empirical evidence on obsolescence patterns (if there is a rational pattern), it must be concluded that the inferiority gradient is not superior to any other techniques in accuracy. There is no less subjective element in any of the approaches. The risks of obsolescence have yet to be translated into measurable units and this is common to all the approaches discussed.

To sum up their arguments, they conclude that no one method is superior to the others in improving on the content of equipment policy. They are all basically restatements of the fact: obsolescence is a hazard to be considered in economy studies.

## Summary and Conclusions

At the outset we mentioned two objectives for this paper. First, we were going to present a brief outline of the replacement theory underlying the MAPI Formula, through an orthodox minimum cost approach. Second, we were to present, discuss, and partially answer some questions and points-of-view presented at the graduate seminar on equipment policy. Space limitations prevent going on. The best thing to do at this point is to abstract some useful generalizations from what has gone before and what limited space has prevented from being presented.

The difficulties that, to this writer at least, seem inherent in the terminology of *Dynamic Equipment Policy* can be avoided simply. An approach through orthodox minimum cost would make the special terminology unnecessary and relate the new concepts to something in the prior experience of the student. The topics of tautology and contradiction in the standard assumptions which were presented are believed to be difficulties which this altered approach would prevent.

There is a great deal more that could be said about the question of validity of the standard assumptions. Indeed, what is perhaps really required is a complete discussion of the scientific method as applied to social sciences. However, our only goal here was to point out that those who challenge the MAPI Formula itself on the basis of empirical validity of the assumptions are arguing rather weakly.

In discussing the criticisms of the standard assumption, we concluded that the emphasis should be on the formula answers themselves. How valid and useful are they? It would appear that *a study of the trends of adoption, progress, methods, and use by industry of the MAPI approach to equipment analysis would be extremely helpful in answering this question.*

Another unanswered question is the broader social effects of widespread adoption of the MAPI Formula. What are its social implications? The effects on the individual firm have been discussed, but it is another thing to completely analyze the broader social and economic effects on the structure of capital investment, etc. There is a relationship here to the question of technological change, obsolescence, capital formation and accumulations, etc. Such a study would contribute to an understanding of the broader social implications of the MAPI approach to equipment analysis.

There are some, it was pointed out, who argue that there are many approaches to equipment analysis and the MAPI Formula is just one of them, equivalent to the others. However, there is really no systematic current practice in equipment analysis to speak of, so if the MAPI Formula is adopted by reason of its support, there will be a contribution to national welfare. In spite of its weaknesses, alleged and real, the MAPI Formula at this time has the greatest possibility of gaining recognition and adoption, critics notwithstanding. Therefore, it is the "best" approach to equipment analysis currently available.

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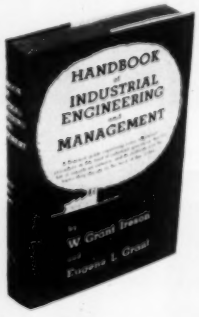


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# Use of Electronic Computers for Business Management

By Herbert J. Groelinger

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To understand how electronic computers can be successfully employed as a powerful management tool requires only a cursory look at the function of management. A most succinct summation of these functions was stated some years ago by Charles E. Wilson, about to assume office of a newly created government defense agency. "Our task," he said, "is to analyze, organize, deputize, and supervise."

As sophisticated a definition as this quickly brings into focus what may be considered the cornerstone of the management task: facts—and all the activities associated with the accumulation, correlation, storage, screening, sorting, and classifying of facts. In an era of scientific management, of absentee ownership, of ever-growing executive organizational patterns, management has developed an almost insatiable thirst for facts.

To satisfy the management appetite, fact processing activities were activated and their growth encouraged until, today, one out of every nine employees is on the office or clerical payroll. Admittedly, this national average fails to separate clerical "production" workers from clerical workers affiliated solely with management or other functions auxiliary to the production process. But since both groups share identical techniques and processes, they may as well be considered as one group.

## Management's Problem

As a result of these conditions, management finds itself in a dilemma. On the one hand it wants—and needs—facts, the raw materials of decision making; on the other hand, it faces daily the total disproportion of costs concomitant with fact processing. It is indeed a serious dilemma, and it can only be solved if management somehow succeeds in getting more for its data dollar.

Similar problems have been solved in the factory, and it is therefore not surprising that management will find its solution coming from the same source and through similar processes which broke the f ry dilemma: mechanization and automatic operation. Of course, office mechanization has been going on ever since the invention of the typewriter in 1868, and has even achieved some startling proportions in certain fields through the use of advanced punch-card equipment. Nevertheless, it is estimated that 85% of office work is still unmechanized, and that real advances will only be achieved through the use of data machinery which is rapid and accurate enough to keep pace with the frenzied rate at which facts are generated by the business process.

## Engineer's Solution

The engineer's answer to the problem is the now rapidly growing family of large-scale electronic digital computers. These machines owe their tremendous power to two facts. One, since they are built with scarcely any moving parts and depend only on the manipulation of electric currents, each individual calculation can be performed at a rate equal to the rate of current transfer. The resultant speeds stagger the imagination: 4,000 to 5,000 additions per second, to cite merely one example. Of even greater significance, however, is the second fact. Not only can each operation proceed rapidly, but the machines are endowed with devices which permit them to store information until this information is needed by the machine for operations. The importance of this lies in the fact that a long series of operations can be fed into the machine and the subsequent machine performance can proceed entirely without human intervention. It is this latter characteristic which is partly responsible for the awe and mystery with which these machines have been received by the public.

## Types of Computers

There are basically two types of machines: the analog and the digital types. The first requires that the numbers of the problem (the data) be converted to measurable values of lengths, voltages, angles, etc. In short, instead of operating upon the numbers themselves, the machine operates with their electrical or mechanical "analogs". Thus it is, in a sense, a measuring apparatus and, as such, subject to human and systematic errors and the limitations inherent in measuring devices.

On the other hand, in a digital computer, operations are performed on numbers expressed as discrete-value digits. In essence, it is a counting machine. The results of computations are likewise in digital form; and, at least in theory, the accuracy and precision of such a device is limited only by the number of digits which can be handled by it. While each type has found its application, the digital machine, because it handles numbers directly, is much more suitable for business data processing.

## Basic Units of Digital Computer

Structurally, a digital computer comprises the following basic units:

1. *Arithmetic Unit*

This unit does the actual computation as instructed. Numbers are referred to this unit by other parts of the machine when specific additions, multiplications, etc., are to be performed.

2. *Memory*

The memory is the device in which the long series of operations and the numbers which represent the actual data are stored until needed by other machine units. Thus the memory holds both instructions to the machine for the performance of operations, and information on which these operations are to be performed. The memory device is divided into many small numbered cells into which the information to be stored is fed.

3. *Control Unit*

This unit has been described as the "traffic cop" of the computer. Its job is to control the flow of information (which is in the form of electrical signals) to and from the other parts of the machine, via the proper wire paths and at the required times.

4. *Input and Output Units*

These units are various paraphernalia by means of which communication between the machine and the operator is established. It is through these devices that data and machine instructions are introduced into the computer and results fed out at the end of a calculation.

## Performance of Computer

To perform a problem on a computer requires procedures very similar to those necessary to perform a problem with human operators. The machine, like the clerk, must be told, step by step, exactly what to do. Just as the clerk receives detailed instructions, the computer must receive a program. This is a step-by-step routine of the individual operations to be performed, which will produce the ultimate, desired solution. A typical program may read something like the following: "Memory locations (cells) #5 and #6 each contain certain numbers. Transfer these numbers from their memory locations into the arithmetic unit, where their values may be compared. Select the larger (smaller) one and multiply it by the number which was brought from memory location #50. Return the result of this multiplication to the memory and store it in location #17. When through, proceed to carry out the next instruction, which may be found in memory cell #21." At cell #21 the computer will find an instruction similar to the example, giving again, in turn, the addresses of the two operands, the type of operation to be performed, the address to which the result is to be sent, and the address of the next instruction.

It is of course clear from the foregoing that before computation begins, the program routine, as well as the data, or operands, must be fed into the machine. The incredible machine speed would be entirely lost if after each operation, the machine were compelled to wait for a human operator to provide the next instruction. Hence the need for a complete program.

## Coding

An additional concession, arising from the problem of language, must be made to the machine. The machine does not speak English. This necessitates the translation of all data and instructions into machine language, a process known as coding. This process entails two operations. First, a system of symbols must be adopted for all operations to be performed. Generally this is taken care of by the machine designers, and it is, in fact, nothing more than a kind of machine shorthand. Instead of saying "Add" or "Subtract" or "Print results", the machine is instructed to perform operations "1" or "2" or "F", etc. Once a particular symbol scheme has been adopted, it is rarely changed for any machine.

The second operation in coding covers the actual translation of data and instruction symbols into machine language. Because of the characteristics of electronic equipment, which responds readily to two steady states of either the presence or the absence of an electrical current, the binary system of notation has been found exceedingly well suited for this purpose. Binary arithmetic is a system based on a scale of ten. Thus, there are only two digits to the system, 0 and 1, a fact which is readily seen to lend itself beautifully to the representation of absence or presence of electrical impulses. Most present digital computers are built around the binary system, so that coding is generally taken to imply the conversion of data and instructions (in machine shorthand symbolism) to the binary system.

The resultant coded program is transmitted into the computer by means of the previously discussed input equipment. The information, in printed form, is first converted into a form which is capable of producing electrical impulses wherever digits appear. Media for this purpose are various magnetic recording devices, such as tape or wire recorders, or punching equipment which may produce a punched tape or card. An adaptation of an ordinary teletypewriter has been successfully employed for producing punched paper tapes. Wherever a digit 1 appears in print, this machine will punch a hole into the paper; a printed zero results in "no hole". When this perforated tape is passed over a reading device, contact between two poles can be established if a hole appears on the tape. The absence of a hole causes the tape to act as an insulator between the contacts, and no current is permitted to flow. In this way, the tape is used to transfer information, converted into the form of electrical currents, into the machine, specifically into the machine memory where it waits until put to use.

## Memory

Internal memory, or storage of these currents, is accomplished either statically or dynamically. In the latter

type, the current is simply circulated and recirculated around a closed path until called for. In static storage, an electrical potential is maintained across two circuit points, which, at the right moment, is used to reproduce the current which originally created the potential. Either or both types may be used in any one machine, the object being only to supply the current pattern as originally received from the punched tape, when the program requires it.

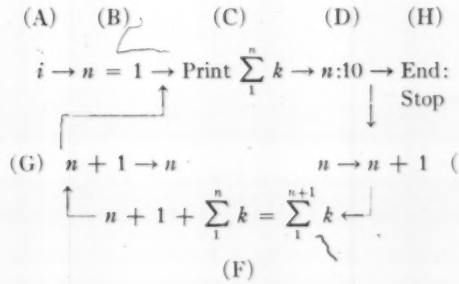
### Arithmetic Unit

The arithmetic unit is a conglomeration of electrical components designed in conformance with the logic of binary arithmetic. The components are made to produce or not produce electrical impulses when excited by the data impulses coming from the memory. For example, if two numbers are to be added, their corresponding pulse trains will be made to enter a component, and pulses will be given off by it depending on the combination of 1's or 0's which were received. If the binary number 10 (decimal 2) and 101 (5) were to be added, the component would first receive a pulse from the last digit of 101. The result, therefore, is 1 pulse. Next a single pulse would be produced by the 1 in 10, and absence of a pulse due to the 0 in 101, resulting again in one pulse. Lastly, the final 1 of 101 produces a 1 pulse. The complete addition is therefore 111 (decimal 7). Provisions are of course made for "carry", "borrow" in subtraction, and the characteristics of the other basic arithmetic operations. To achieve greater speeds, certain operations, which could be reduced to the basic ones, have been included in the repertoire of some machines as fundamental operations. Naturally machines so equipped are more involved. A basic repertoire, including input, print, subtraction, addition, multiplication, division, algebraic and absolute comparisons, logical product and transfer, and rounded multiplication, appears to be quite adequate for some business uses.

### Sample Problem

A sample problem will be helpful to describe the entire problem-solving procedures. The problem consists of producing the sums which will result from adding a number to its next higher neighbor, then adding the next consecutive number to this sum, etc., up to 10. In mathematical parlance, this is called producing the first 10 triangular numbers.

The first step is to reduce the problem to mathematical formulation so that the correct sequence of operations and the necessary constants can be determined. In this problem, the $n^{th}$ triangular number can be defined as $\sum_{k=1}^{n} k$. To aid in understanding the logical organization of the program, a block or flow diagram, which is an overall picture of the calculation procedure, is useful before actual coding is undertaken.


(A)
(B)
(C)
(D)
(H)
$i \rightarrow n = 1 \rightarrow$ Print $\sum_1^n k \rightarrow n{:}10 \rightarrow$ End: Stop
(G) $n + 1 \rightarrow n$
$n \rightarrow n + 1$ (E)
$n + 1 + \sum_1^n k = \sum_1^{n+1} k$
(F)

Verbally, this diagram states the following: After the intake operation, A, is completed, and all numbers have been stored in their assigned memory cells, pick the first number, calling it $n$, as shown in Operation B. Perform the arithmetic operation shown in C, that is, get the sum of $k$ as $k$ goes from 1 to 11, and print out the result. At D, compare the present $n$ with the maximum number of the problem, 10, and determine which is larger. If $n$ is smaller than 10, the end of the problem has not been reached, therefore proceed to E. Consider the value of $n$, and pick from the memory the number which is greater than $n$ by 1. At F, this greater number is added to the sum of $k$ as $k$ goes from 1 to $n$, as shown in mathematical symbols. This sum is temporarily stored. To keep instructions to a minimum, i.e., to allow the instructions used so far to be reused, the $n + 1$ number is given the new title of "$n$" at step G. For the ensuing cycle, then, $n$ is actually the old $n + 1$ number. At C, the sum of $k$ is obtained and printed, as $k$ goes from 1 to the $n$. It will be seen that this sum is actually the sum already obtained at F, which was temporarily stored. It is taken out of storage and printed, and the cycle is repeated until $n = 10$, at which point Operation H is performed, and the computer stops.

The following table, showing the first four cycles, will further clarify this routine:

| Op. | Notation | Description | Actual Numerical Value |
|---|---|---|---|
| A | $i$ | Data Intake | |
| B | $n = 1$ | 1st number from memory | 1 |
| C | Print $\Sigma_1^n k$ | Print Out | 1 |
| D | $n{:}10$ | Compare $n$ to 10. If smaller go to E | smaller |
| E | $n \rightarrow n + 1$ | Pick next larger number from memory | 2 |
| F | $n + 1 + \Sigma_1^n k = \Sigma_1^{n+1} k$ | Obtain sum up to $n + 1$ and store | 3 |
| G | $n + 1 \rightarrow n$ | New "title" $n$ to old $n + 1$ number | 2 |
| C | Print $\Sigma_1^n k$ | Print sum obtained in F | 3 |
| D | $n{:}10$ | Compare $n$ to 10. If smaller go to E | smaller |
| E | $n \rightarrow n + 1$ | Pick next larger number from memory | 3 |
| F | $n + 1 + \Sigma_1^n k = \Sigma_1^{n+1} k$ | Obtain sum up to new $n + 1$. Store | 6 |
| G | $n + 1 \rightarrow n$ | New "title" to $n + 1$ number | 3 |
| C | Print $\Sigma_1^n k$ | Print sum obtained in F | 6 |
| D | $n{:}10$ | Compare $n$ to 10. If smaller go to E | smaller |

| | | | |
|---|---|---|---|
| E | $n \rightarrow n+1$ | Pick next larger number from memory | 4 |
| F | $n+1+\Sigma_1^n k = \Sigma_1^{n+1} k$ | Obtain sum up to new $n+1$. Store | 10 |
| G | $n+1 \rightarrow n$ | New "title" to old $n+1$ number | 4 |
| C | Print $\Sigma_1^n k$ | Print sum obtained in F | 10 |
| D | | | |
| E | | | |
| F | | | |
| G | | | |

The next step in the procedure calls for the adoption of the machine shorthand. The operations involved in this problem are: Addition, Print, and Comparison. The short symbols 5, F, and D will be used to signify these operations, respectively. Assuming that the 10 values which will be assumed by $n$ during the problem will be stored in memory locations 21 to 30, and that instructions will be stored consecutively in cells 1 to 10, we have:

| | Description | Cell No. | Code | |
|---|---|---|---|---|
| 1. | Address of $n$ | 21 | 21 | 21F2 |
| | Print | — | F | |
| | Address of next instruction | 2 | 2 | |
| 2. | Address of $n$ | 21 | 21 | 2129D3 |
| | Address of 10 | 30 | 29 | |
| | Compare | — | D | |
| | Address of next instruction | 3 | 3 | |
| 3. | Address of $n$ | 21 | 21 | 21225314 |
| | Address of $n+1$ | 22 | 22 | |
| | Add | — | 5 | |
| | Address where sum is to be stored | 31 | 31 | |
| | Address of next instruction | 4 | 4 | |
| 4. | Address of old sum | 31 | 31 | 31F5 |
| | Print | — | F | |
| | Address of next instruction | 5 | 5 | |
| 5. | Address of $n+1$ | 22 | 22 | 2229D6 |
| | Address of 10 | 30 | 29 | |
| | Compare | — | D | |
| | Address of next instruction | 6 | 6 | |
| 6. | Address of $n+2$ | 23 | 23 | 23315327 |
| | Address of old sum | 31 | 31 | |
| | Add | — | 5 | |
| | Address where new sum is to be stored | 32 | 32 | |
| | Address of next instruction | 7 | 7 | |
| 7. | Address of old sum | 32 | 32 | 32F8 |
| | Print | — | F | |
| | Address of next instruction | 8 | 8 | |
| 8. | Address of $n+2$ | 23 | 23 | 2330D9 |
| | Address of 10 | 30 | 30 | |
| | Compare | — | D | |
| | Address of next instruction | 9 | 9 | |
| 9. | Address of $n+3$ | 24 | 24 | 242353310 |
| | Address of old sum | 32 | 23 | |
| | Add | — | 5 | |
| | Address where new sum is to be stored | 33 | 33 | |
| | Address of next instruction | 10 | 10 | |

(etc.)

Finally, the coded instructions and the data are converted to binary form, a tape will be punched by means of which the entire data are fed into the machine, and the computer proceeds to grind out the answers.

## Application

It will be readily appreciated that with proper modifications in the data, the simple procedure of this example can find direct application to several management problems. An ideal application, for example, would be the building up of a synthetic time standard for a production process. With only a slightly more sophisticated routine, several different methods could be compared, and the shortest one selected. In somewhat the same manner, total payroll costs or raw materials costs can be obtained. Were a subtraction operation included in the code, by comparing relative machine speeds, the machine could at once determine extra shift operations of bottleneck equipment, and thus also arrive at lead times necessary from station to station, as well as compute the total capital tie-up in the process. In short, the use of even this most elementary routine provides some very important answers which certainly some management is seeking.

More complex routines are, of course, required for more complex problems. The important fact to realize, however, is that any problem which can be expressed symbolically can be solved in this manner. A look at a selected list of tasks to which digital machines may be applied commercially will actively support this point.

## Examples

American Airlines uses a digital machine to maintain an accurate up-to-the-second inventory of available seats on all flights originating in New York City and to reduce to an instant the time it takes to book a reservation. A central memory stores the available seating capacity on more than 1,000 flights, covering a period of about ten days. The ticket agents, in remote parts of the city, are provided with small pushbutton sets, by means of which they have access to all data stored in the memory. Assuming that a passenger desires three reservations from New York to Washington, the agent first selects a so-called destination plate from a file. This gives the number, departure time, origin, and destination of eight flights, and when inserted into a notch in the agent's set, causes contact to be established with the specific areas of the memory containing the relevant information. When the agent presses the proper keys indicating date and number of seats required, the computer responds—in about $\frac{3}{4}$

of a second—which of the eight flights have at least three vacancies on the desired date. This is indicated by signal lights on the agent's set. If the passenger chooses one of the flights, a key is set to "Sell", and a button pressed corresponding to the flight. One quarter of a second later, a green light on the agent's set indicates completion of the transaction. Direct selling, without prior availability check, may also be made. In this case, should the desired flight be sold out, an amber light would appear on the agent's set. Cancellations are made similarly, with the vacated seats returned to the inventory.

A machine at the Pentagon is used to solve problems in Program Planning. Data in the form of available manpower, facilities, equipment, funds, and supplies are introduced into the computer, whose job it then is to determine whether these input factors can support a stipulated war plan. To complicate the problem, one or several of the inputs are usually to be maximized or minimized. Put another way, the problem is to determine the quantities of all inputs needed for a series of time periods to carry on a specific program, with the use of one or more items to be optimized. At one time, manual computation of such programs took so long that it was impossible to consider alternative programs equally compatible with the input conditions. The computer has not only removed this obstacle, but it has made it possible to perform the entire task with about 50 people. Yearly costs have been reduced from $750,000 to $250,000.

Several national magazines' entire operations, covering record keeping for over 1,000,000 subscribers, renewals, billings, and mailings, are planned to be handled by a digital computer, as are many companies' entire accounting activities.

At the U. S. Bureau of the Census, a machine has been aiding in the promulgation of demographic statistics. The first problem to be assigned to the computer was the production of a part of the Second Series Population Tables for the 1950 census. The data involved the equivalent of 11,000,000 punched cards. The entire operation was done automatically except for tape changes and handling of the cards at the original transcription of the data to tapes.

A host of other blue-chip company names could be added to the above. Dozens of demonstrations have been made of the business capabilities of digital machines. They range all the way from completely automatic time studies to air traffic control; from preparation of premium notices, dividends, and commissions for insurance companies to a phased raw materials program for the Navy's new ship construction plans; from statistical analyses for a market research firm to presidential election forecasts.

Manufacture of digital machines has already attained a feverish pitch among competing office machine producers, some of the aircraft firms, and small specialized companies. Altogether there are probably over 100 firms in the industry. Prices, depending on the complexity of the gadgets, vary all the way from approximately $15,000 to over $4,000,000.

**Conclusion**

In conclusion, lest the new business revolution foreshadowed by these machines be expected tomorrow, a few cautionary remarks are in order.

It must be remembered that the computers were originally designed for scientific computations. The difference between these and business computations lies in the amount of data to be processed. While internal computation for scientific purposes is often formidable, the actual information communicated to the machine is usually small, often no more than a handful of equations. With business data it is just the opposite. Huge quantities of information are fed into and out of the machines, while internal computations, although numerous, are fairly simple. This poses the need for more efficient input and output appendages than have hitherto been developed. At present the disparity between input speeds and internal computing speeds is of the ratio of 1:100, a disparity which can be quite uncomfortable, especially in view of the high cost of the equipment. Techniques for minimizing this disparity have, of course, been developed, but the problem is basic and needs a good deal of further study.

Another major stumbling block to the successful use of these computing Goliaths arises from management itself. Unfortunately, there are few executives who fully understand the objectives of many data processing activities, and it is just such understanding which is required. It will not suffice to add electronic appendages to the existing data processing structure. What is necessary is a complete analysis of these activities and their reorganization to suit the electronic tools available. True functional analysis, in terms of the end objectives of the processing activities, is a byword of the successful integration of machines of this type. To industrial engineers this is nothing new, but to management, which has not always appreciated the fundamentals of "eliminate, combine, simplify, change sequence", the concept may come slowly, especially since it will have to be applied at the very highest levels of the organization.

Thus, electronics brings with it the additional advantage of forcing a grand-scale business house cleaning.

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# The Relationship Between Heart Rate and the Intensity of Work for Selected Tasks*

By H. H. Young

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As a person performs work, either mental or physical, certain physiological changes take place within the human body. One rather easily measurable change is the heart rate, which is known to increase above an "at rest" rate as work is performed. Dr. Lucien Brouha, Chief Physiologist at the Haskell Laboratory for Toxicology and Industrial Medicine of E. I. Du Pont, has made many significant research contributions in the area of heart rate recovery following work. Heart rate recovery can be defined as the rate of return of the heart beat to a pre-exercise level following a period of physical work. In addition to the work load, such factors as temperature, humidity, impervious clothing, sex, age, state of nutrition, physical condition, time of day, self-consciousness, emotional state, accumulated fatigue, and training have all been found to affect either the level of heart rate during exercise or the rate of heart recovery following exercise.

At Purdue University, we became interested in the possibility of using changes in heart rate as a measure of the pace which an operator uses in performing a job, relative to the physical difficulty requirements of the job. After a thorough study of the literature pertaining to industrial physiological measurement and work efficiency, we decided to investigate the possibility of using heart rate as an objective method for rating operator performance on jobs of varying physical difficulty.

Dr. Brouha's work has already shown that recorded changes in pulse rate provide satisfactory measurements of the physiological expenditure that is required by a given job. However, Dr. Brouha has been primarily interested in heart rate recovery as a means of evaluating job factors which contribute to fatigue. In our case, we were primarily interested in finding the correlation between heart rate, following a timed interval of work, and the pace of the operator during the work cycle—for particular job requirements.

In order to study the relationship between heart rate and the intensity of work, it was important either to isolate the variables affecting heart rate or to accept them as part of an experimental error. The effects of temperature, humidity, impervious clothing, sex, age, and training were all nullified, or at least minimized, by control of these factors in the experiments. In the first study made, all of the data was taken at essentially the same time of day, eliminating the effect of this variable. In a second study, the time of day was included as a variable factor in recording and analyzing the data. Variations in such factors as self-consciousness, emotional state, and physical condition were minimized as much as possible.

## First Study

In the first project undertaken, it was desired to investigate human heart rate recovery as a measure of the rate of human work. The first step undertaken was the development of a standard task in which the operator's pace could be easily controlled. The task which was developed consisted of operating a small hydraulic hand pump in a closed fluid system. The operator's pace could be arbitrarily fixed by requiring a given number of strokes per minute in time with a metronome. Figure 1 illustrates the experimental setup.

Fourteen male graduate students, between the ages of 23 and 31, served as operators in pumping the handle of the apparatus at prescribed work paces of 80, 100, and 120 double pump strokes per minute. The middle pace of 100 strokes per minute was selected on the basis of what most of the operators considered to be about normal for the task. A ten-minute rest period was provided before the first pace was tried and between each work-cycle at different paces. The time period per work-cycle was two minutes, at the end of which the heart rate was counted, using a stethoscope, and the time in seconds for 30 beats was measured with an electric stopwatch. Again at one, two, and three minutes after the cessation of work, a heart rate measurement was made. This procedure was repeated for each of the three selected paces and for a fourth pace which each operator selected as his best working pace. The order in which the paces were presented was randomized over the fourteen operators. Pre-experiment study indicated that the ten-minute rest period between work-cycles was sufficient to overcome the effects

* This paper is based in part upon the work of Messrs. L. J. Deney and H. A. Tarabishi, who completed Master of Science research work under the guidance of the author.

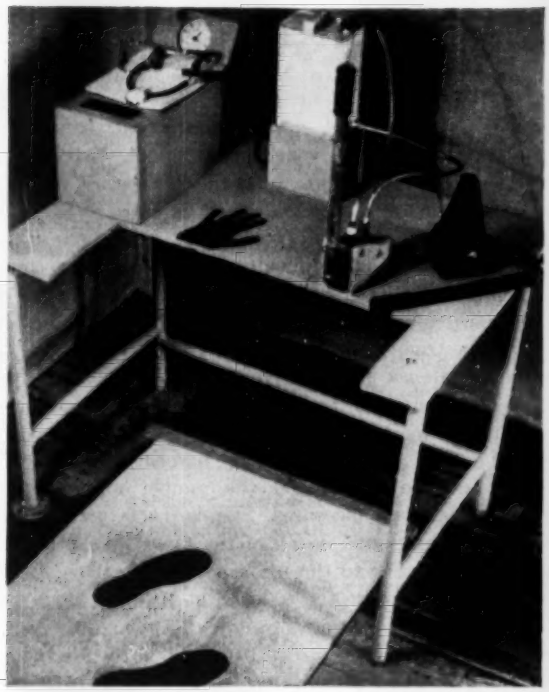


FIG. 1. Experimental Set-up

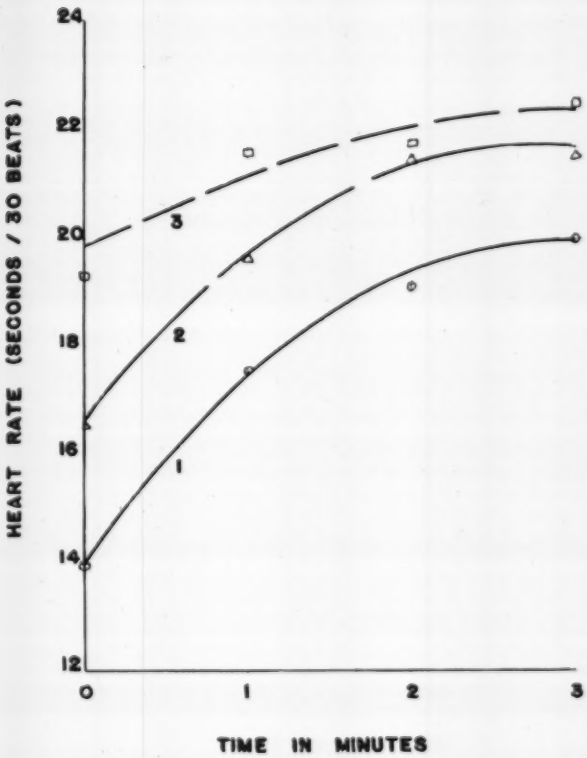
of fatigue and to allow the heart rate to return to near normal. The results of this study consisted of heart recovery curves for each operator, a composite or mean set of heart recovery curves, an analysis of variance for significance of the effect of pace upon heartrate, and the computation of correlation coefficients for pace upon heart rate.

Figure 2 illustrates the mean heart recovery curves for the operators, for the three selected paces of 120, 100, and 80 double pump strokes per minute. These curves were developed by averaging the data for the fourteen operators, plotting the points, and fitting curves by eye. It may be noted that the heartrates, in seconds per 30 beats, are consistent with the pace used over the entire recovery period observed. This was true for each of the operators as well as for the mean. In other words, as the pace increased, the number of heartbeats per minute increased for all of the operators and the mean at the zero readings, taken immediately following work. However, on the individual operator curves, the relationship between heart rate and pace was not always consistent. In some cases the heart rate curves crossed at two to three minutes after the cessation of work, indicating the influence of accumulated fatigue, emotional factors, or other factors on the recovery data.

## Analysis

An analysis of variance for a one-way classification of data was made to test the hypothesis that the means of the heart rates, taken immediately following work, were not significantly different for each of the three selected paces. The hypothesis was disproved when the test ratio showed an "F" value of 15.8 compared to a criterion "F" value at the 5 percent level of significance of only 3.24. Thus pace was shown to have a highly significant effect upon heart rate in this experiment.

Next, correlation coefficients were computed directly from the data for the relationship between heart rate at the cessation of work and at one minute after work, and the pace used by the operator during the work. These coefficients ranged from .889 to .999 for the fourteen operators immediately following work; one minute after the cessation of work the coefficients ranged from .363 to .999. Thus, the highest correlation between heart rate and pace appears to exist immediately after a period of work. Table 1 shows the product-moment correlation coefficients for the fourteen operators at the cessation of work and at one minute following work.




| | Heart rate in seconds per 30 beats at various times after working | | | |
|---|---|---|---|---|
| | 0 delay | 1 min. | 2 min. | 3 min. |
| Pace 1 | 13.99 | 17.55 | 19.12 | 20.02 |
| Pace 2 | 16.55 | 19.62 | 21.40 | 21.47 |
| Pace 3 | 19.27 | 21.54 | 21.72 | 22.44 |

FIG. 2. Mean Heart Rate Recovery Curves for Fourteen Operators Working at Three Paces on a Standard Task.

TABLE 1

*Product-Moment Correlations between Operator Pace and Heart Rate on a Standard Task Immediately Following the Cessation of a Two-Minute Work Period and One-Minute after the Cessation of Work*

| Operator | Correlations | |
|---|---|---|
| | $r_0$ | $r_1$ |
| 1 | .9910 | .9641 |
| 2 | .9291 | .9972 |
| 3 | .9873 | .9918 |
| 4 | .9900 | .9802 |
| 5 | .9950 | .8081 |
| 6 | .9903 | .9922 |
| 7 | .9992 | .9964 |
| 8 | .9886 | .3629 |
| 9 | .9941 | .9944 |
| 10 | .8887 | .9999 |
| 11 | .9886 | .9958 |
| 12 | .9803 | .9537 |
| 13 | .9922 | .4645 |
| 14 | .9972 | .9200 |

## Results

The results of this first study were most encouraging and indicated the desirability of investigating the relationship between heart rate immediately following a known period of work, and the intensity of the work. Intensity was defined, for purposes of our further research, as the combination of operator pace with the physical (and perhaps mental) requirements of the particular job on which the operator is working. In other words, intensity is what is rated in pace or effort rating systems.

## Second Study

Four different tasks were selected for study in the second project, one of which was used as a standard task in studying work intensity-heart rate relationships. This standard task consisted of moving a push-pull handle, attached to a device by means of which a variable amount of resistance to movement could be adjusted. The handle was moved in a horizontal plane, force being required in only the push direction.

The other selected tasks were: 1. a man walking on a level floor, 2. a man climbing stairs, and 3. a man lifting a 30-pound load from the floor, carrying it for twenty-five feet, and putting it back on the floor. Each of the four tasks was performed for a period of two minutes, followed by a ten-minute rest period to allow the heart rate to return to near normal. The task selected as a standard was performed by each operator at three different paces, these being 90, 110, and 130 double strokes or cycles per minute. The 110 cycle per minute pace represented approximately normal for the operators selected. Each of the other three tasks was performed at one of three preselected paces: 110 steps per minute for the *walk* task, 90 steps per minute for the *walk with load* task, and 130 steps per minute for the *climbing stairs* task. The order in which the task-pace combinations were presented to the 16 student operators was randomized. No special attributes or qualifications were considered in selecting the operators; however, it is certainly recognized that the sample of operators could not be considered random. Even so, it was considered desirable to treat the "operator" variable as a random factor in the analysis of variance.

In this study, the primary objective was to see if the combined effects of task difficulty and operator pace could be predicted from heart rate measurements, independent of the particular operator thus measured. If such were found to be true, then conceivably it would be possible to use heart rate as an objective and scientific means for rating operator performance on jobs of varying physical difficulty. As in the first project, the operator was asked to work against a metronome pace; immediately following each two-minute work period, the number of seconds for 30 heart beats was measured. Standard instructions and a brief training period on all of the tasks were provided each operator prior to the measured observations. Eight of the operators made the test run at 10:00 A.M. in the morning (on various days), and the remaining eight operators made the test run at 2:00 P.M. in the afternoon. The *Time of Day* was considered as one of the variables in the analysis. Table 2 shows the recorded data for eight of the sixteen operators. Only one reading was taken for each task-pace combination.

## Analysis

The data was subjected to the analysis of variance technique using a three-way classification of data. Since only one reading was made per cell, the error is lumped with the interactions. *Time of Day* and *Task* were considered as fixed factors; *Operator* was considered as a random factor. The analysis of variance table for this study is shown in Table 3.

## Results

Through this study, it was shown that the task difficulty-operator pace factor, simply noted as the *Task* factor in the analysis, had a highly significant effect on the measured heart rates at both a 5% and a 1% level of significance. The effect of the particular operator studied upon the heart rate data was just insignificant at the 1% level, but was significant at the 5% level of significance. The *Time of Day* factor was also insignificant at the 1% level but significant at the 5% level. The Task-Time of Day Interaction was significant at both the 1% and the 5% level, indicating that the *Task* factor and the *Time of Day* factor were not independent of each other in affecting operator heart rates. The most important conclusion which can be drawn from this study, of course, is that the intensity of work on a task can be predicted from direct measurements of heart rate following work, at the 1% level of significance and within the limitations of this experiment.

## Proposal & Speculation

It is planned to continue research in this area in an attempt to reduce the "operator" effect on the data. It is strongly felt that this might be accomplished by considering the "at rest" heart rates of the operators, or the recovery curves of the operators, to correct or adjust the heart rates obtained after work. We intend to use a covariance analysis in our next study to pull out the physical differences from the operator variable.

In any case, we have already a good indication that heart rate may be used to "rate" operator performance. In an industrial situation, it is conceivable that a standard task could be developed which would be delivered to the operator's worksite on an industrial truck of some type. Some pace on this standard task could be agreed upon as the *normal* level of work intensity for the plant. To "rate" the operator, several measures of heart rate would be made at the worksite immediately following or during the actual observation of element times. The operator would first be asked to stop work and rest for a period of ten minutes. At the end of this period, an "at rest" measure of heart rate would be made. The operator would then be asked to perform his job at his usual rate of work for some specific interval of time. It would be the responsibility of the analyst to see that the element times during this period were consistent with the element times recorded during the time study observation period. A small microphone strapped to the chest of the operator could be used to pick up the heart beat, which would be amplified and fed into a chart recorder. At the end of this work period, the heart rate would be recorded for a period of four or more minutes on the chart record. This would provide not only the heart rate at the cessation of a timed period of work but also the heart recovery curve for the individual.

The operator would receive a full ten-minute rest period including the portion measured for a heart recovery curve. The operator would then be asked to perform the standard task in time with a metronome at the preselected level of intensity considered normal, for the same interval of time used on the task being studied. Following this second work period, a similar record of heart rate and heart rate recovery would be made. With this data, it should then be possible to "rate" the operator's performance of his job to the standard task and pace considered *normal*. This rating would require conversion scales into percentage adjustments on the averaged element time observations. One rating would probably be applied to all elements.

Let me hurry to remark that we have by no means shown that this is a feasible way of rating operator performance. However, we have some indications that it might be feasible, and to this end we plan to continue our research work. Comments pertaining to the methodology or usefulness of this investigation will be most welcome.

TABLE 2

*Data on Operator Pace, Heart Rate, and Task Order for Four Different Tasks, Observed on Eight Operators between 10:00 A.M. and 11:00 A.M. in the Morning*

Morning

| Operator | Task Order | TIME FOR: | | | (sec./30 beats) | |
|---|---|---|---|---|---|---|
| | | Pace | Standard | Walk | Walk with Load | Climbing Stairs |
| 1. | 6, 1, 5, 2, 3, 4 | 90 | 17.70 | | 16.02 | |
| | | 110 | 16.30 | 25.00 | | |
| | | 130 | 14.46 | | | 13.74 |
| 2. | 5, 1, 6, 2, 4, 3 | 90 | 16.80 | | 15.60 | |
| | | 110 | 15.72 | 22.32 | | |
| | | 130 | 14.28 | | | 13.92 |
| 3. | 6, 1, 5, 3, 2, 4 | 90 | 19.98 | | 17.34 | |
| | | 110 | 18.96 | 23.70 | | |
| | | 130 | 16.08 | | | 16.20 |
| 4. | 6, 4, 1, 5, 2, 3 | 90 | 19.98 | | 18.00 | |
| | | 110 | 19.92 | 22.80 | | |
| | | 130 | 21.84 | | | 16.26 |
| 5. | 5, 4, 3, 6, 1, 2 | 90 | 18.06 | | 13.20 | |
| | | 110 | 17.34 | 19.20 | | |
| | | 130 | 15.00 | | | 12.00 |
| 6. | 6, 5, 1, 2, 4, 3 | 90 | 19.08 | | 12.60 | |
| | | 110 | 17.34 | 19.20 | | |
| | | 130 | 16.80 | | | 13.92 |
| 7. | 4, 5, 3, 6, 1, 2 | 90 | 13.08 | | 12.54 | |
| | | 110 | 12.12 | 17.70 | | |
| | | 130 | 12.12 | | | 12.54 |
| 8. | 5, 1, 6, 2, 4, 3 | 90 | 15.05 | | 15.90 | |
| | | 110 | 16.00 | 20.70 | | |
| | | 130 | 15.50 | | | 15.00 |

TABLE 3

*Analysis of Variance Table for the Variables of Time of Day, Operator, and Task in their Effects upon Operator Heart Rates*

| No. | Source of Variation | Degrees of Freedom | Sum of Squares | Mean Square | Ratio | Comuted F | Criterion F (1%) |
|---|---|---|---|---|---|---|---|
| 1. | Time of Day | 1 | 113.1564 | 113.1564 | 1/2 | 7.8719 | 8.86 |
| 2. | Operator | 14 | 201.2468 | 14.3747 | 2/5 | 2.5391 | 2.54 |
| 3. | Task | 3 | 566.2675 | 188.7558 | 3/5 | 33.3414 | 4.29 |
| 4. | Task—Time of Day Interaction | 3 | 129.1420 | 43.0473 | 4/5 | 7.6037 | 4.29 |
| 5. | Task—Operator Interaction | 42 | 135.8714 | 5.6613 | | | |

Note: There was no three-way interaction since each operator worked at only one of the two times. With only one reading per cell the error term is lumped with the interactions.

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# INSTITUTE INTERESTS

## CHICAGO CHAPTER

The Chicago Chapter opened its 1956-57 season on September 11 with a tour of United Airline installations. Members observed among others, the Demehl pilot trainer which duplicates emergency flight conditions, the handling of air freight and United's flight kitchen methods.

The tour was followed by a dinner meeting at which the group was addressed by Mr. Warren Alberts, United's Director of Industrial Engineering. Mr. Alberts outlined Industrial Engineering's role in the company's operations, indicating the diverse phases of engineering study which are carried on by his group. Audience interest centered on the consultive type role that United Airlines Industrial Engineering Department assumes within the Airline's organization.

Chapter President A. E. Aronson and Program Chairman T. R. Woolard announced the following chapter meetings

October 9 Subject: *Operations Research*
Speaker: Mr. John Roseboom
Booz, Allan & Hamilton

November 13 Subject: *Incentives in the Office*
Speaker: Mr. R. Scheuer
Eli Lilly & Co., Minneapolis

December 11 Subject: *Work Simplification Workshop*
Directed by: Mr. A. H. Mogensen
Mr. Mogensen will conduct an all-day work simplification session.

## DALLAS-FORT WORTH CHAPTER

The officers and members of the Dallas-Fort Worth Chapter decided to continue their meetings throughout the summer rather than adjourn as some societies do. The programs selected for the summer months included a panel discussion conducted by Mr. George McNew of A. Brandt Co. of Fort Worth with a panel consisting of Jim Bourland, "Tex" Dodson, Dave Hoke, and Don Elliott. This panel type program was very well received as this type program has been in the past. The members had a chance to participate in the discussion and a very informative time was had.

The Technical Seminar held on "Punched Card Systems" conducted by Les Faulkner of the Dallas-Fort Worth Chapter provided technical information on this subject for our members. This was in line with the chapter's overall objective of providing both specialized and general subjects for their various meetings.

Dr. Virgil A. James, co-ordinator of management development for Chance Vought Aircraft, Inc., gave a very interesting talk at the September 5 meeting on "A Master Plan for Management Development."

Our chapter was very fortunate in obtaining Mr. Allan H. Mogensen as a speaker for a special meeting held in Fort Worth on September 11. Mr. Mogensen addressed the group on "Work Simplification," a field in which his works are well known to all industrial engineers. There was an excellent turnout of some 120 persons with some people coming from as far as 150 miles for the special meeting.

Preliminary plans have been made for the spring management forum, the 3rd annual such affair to be conducted by the Dallas-Fort Worth Chapter. Mr. Ross Hammond of Texas Electric Service Company has been selected as chairman of the management forum. These forums continue to gain in popularity with some 200 persons attending the 1956 sessions.

## FORT WAYNE CHAPTER

The Fort Wayne Chapter had an interesting approach to their Seminar on "How's Your Attitude?" held on September 10, 1956. The following questions were to be answered in 25 words or less.

1. What in your opinion makes a good Industrial Engineer?
2. How much management authority should an Industrial Engineer take?
3. Suppose a foreman tells you he thinks your process or time stinks. What would you tell him?
4. You are working on a special rush job for the plant manager and you get a call from the floor that a fixture or equipment is holding up production. What would you tell him?
5. You are assigned on a cost reduction project. You tell the Department head from whom you expect cooperation what you are doing. He tells you it is none of your business. What would you tell him?

How do you feel about the following:

Overtime: When necessary____Any time____Not crazy about it____

Paper work: I don't like it too much____
It doesn't bother me____

Here is the general consensus of opinion:

1. Common sense—education—experience—personality—cost conscious—a good organizer and one who follows up assignments—defines and makes reports—sells oneself—has curiosity, ingenuity, integrity. (Where is this fellow?)
2. Takes all the responsibility his position warrants, and if additional problems arise, defines and sells the recommended solutions to the management. Also, feel your way through.
3. Why Joe?—then—O.K., we had better recheck and if we are in error, we will rectify. If in error, thank him for calling it to your attention. (Where is this guy?)
4. If you can't get help, let the plant manager decide. It is true the Industrial Engineer knows production comes first, but let him know.
5. As an Industrial Engineer, cost reduction is an important phase of your job. If persistent, ask him to put it in writing. He might—you're protected.

*Overtime.* When necessary. However, a man should be told when he is hired, for example, in forty hours you are expected to complete your work and maybe special jobs requiring overtime.

*Paper Work.* It doesn't bother me. We are convinced it's here to stay. There are tons of it between the birth certificate and the death certificate, but it sure bothers us when it is unnecessary.

## LOS ANGELES CHAPTER

This year's program and activities are already in high gear at this time under the able direction of President Arnold Cowan and Vice-President Wil Whitson.

The Program committee, headed by Don Mihelic, is following a unique approach in diversifying the meetings in an effort to create the maximum interest and attendance. The general format of the meetings has five distinct components as follows:

1. Technical clinic
2. Business meeting
3. Film—general and non technical (sports, travel, etc.)

4. Speaker—general, scientific, business and engineering interest (missiles, atomic reactors, aircraft, electronics, etc.)
5. Speaker or panel—specific topics for Industrial Engineers

To provide its members with a media for exchanging local chapter ideas and further "knit the unit", the Publicity committee, directed by Stan Wolfberg, is publishing a monthly Newsletter. Features will include:

1. Message from chapter president
2. Summary of director's meetings
3. Summary of committee reports
4. Personal news items
5. Employment opportunities
6. Special features.

Stan Optner's Education committee has directed a "double barreled attack" at the members in first, establishing a "new speaker" clinic for the development of speaking ability; and second, providing a Speakers' Bureau to supply talent for outside groups; and third, participating in an industrial engineering project for some community program.

It's too early to announce any formal plans for the 1958 National Conference to be held in Los Angeles, but suffice to say, that detailed planning is well under way to make this an outstanding event.

The year's dinner meeting activities were "kicked off" with a most interesting joint meeting with the local chapter of the American Society of Quality Control.

Mr. Obert B. Moan, A.S.Q.C., supervised a Motion Study Clinic, featuring Mr. Don Wheeler, A.I.I.E., Robertshaw-Fulton Controls Co., and a film, "The Foreman Discovers Motion Study."

Mr. Art Chilman, A.I.I.E., supervised the Work Sampling Panel, which was directed by Mr. Leo A. Aroian, A.S.Q.C., Hughes Aircraft, and featured the personalities of Dr. Ralph Barnes, A.I.I.E., University of California at Los Angeles, Dr. Edward Coleman, A.S.Q.C., University of California at Los Angeles, and Mr. Robert Edgecumbe, A.I.I.E., Virtue Bros. Mfg. Co. The subject matter included the fundamental principles of the statistics as applied to work sampling; the design of work sampling systems and the general applications of these systems to industry; and an industrial application of a work sampling system.

The October dinner meeting inaugurated the new program ideas mentioned above revolving around a varied theme of short subjects.

Mr. William Sheridan, Supervisor of Contract Specifications, North American Aviation, Downey, presented an outstanding talk, "Guided Missile—A Present with a Past and a Future." His subject included a review of the background of guided missiles from their inception during World War II, the reaction of the Germans and the English to the V-2, and a closer look at the unclassified plans relating to the earth satellite programs, present and potential.

Mr. Henry T. Larson, Senior Member of the Technical Staff, Ramo-Wooldridge Co., spoke on the "Impact of Electronic Digital Computers on Industrial Engineering". His topic encompassed the general increases in the use of computers, the specific area of usage that affects the Industrial Engineer, new developments in the field, and specific examples of current applications.

Topping off the variety of the program was the color film of the "Hi-Lites of the 1955 Los Angeles Rams' Football Season."

## MICHIGAN STATE UNIVERSITY

The Eighth Annual Industrial Engineering Conference was held on the University campus on September 10-14. The popular combination of general sessions and discussion groups was presented. This plan offered an opportunity for the entire group to meet together several times during the week for a talk of general interest. During the balance of the week, the conference was divided into small discussion groups on various phases of Industrial Engineering. Topics for the sessions were selected with the objective of presenting the latest and best in Industrial Engineering to practicing men in industry. Topics which were presented during the general sessions by nationally known leaders in their respective fields were:

The Anatomy of Industrial Engineering
Industrial Engineering—Labor's Point of View
Management Aspects of Automation
The New Look in Industrial Engineering

Discussion groups were held in the following subject areas:

Fundamentals of Industrial Engineering
Advanced Motion and Time Study
Statistical Methods in Industrial Engineering
Linear Programming
Plant Layout and Materials Handling
Chief Industrial Engineers' Seminar

## OKLAHOMA CITY CHAPTER

Our chapter had its first organizational meeting on March 8, 1956, and our charter was granted on April 23, 1956. We have a current total of thirty-five members.

Our first four programs have been as follows:

1. "The Industrial Engineer and His Professional Status" by William J. Collins, President, Central Oklahoma Chapter, Oklahoma Society of Professional Engineers.
2. Report on the National Convention by Wilson J. Bentley, Southwest Regional Vice-President.
3. A description of I.E. work in Oklahoma industries by four members of our chapter.
4. A tour of the Sylvania Electric Products, Inc. plant in Shawnee, Oklahoma.

The officers are: Ray M. Crouch, President; Don K. Andrews, Vice President; Ralph L. Good, Secretary; C. O. Hollingshead, Treasurer; W. R. Johnson, one year director; Norris A. Griffith, one year director; Robert W. Hamilton, two year director; Terry S. Leard, two year director; Sam Austin, three year director; Kenneth C. Knight, three year director.

## PHILADELPHIA CHAPTER

Regular meetings of the Philadelphia Chapter will generally be held on the third Wednesday of each month at the Atlantic Refining Company, 260 South Broad Street. Meetings will begin promptly at 7:15 p.m. The following is a list of the regular scheduled meeting dates for the Philadelphia Chapter:

| Meeting Date | | Meeting Date | |
|---|---|---|---|
| September | 19, 1956 | February | 20, 1957 |
| October | 17, 1956 | March | 20, 1957 |
| November | 28, 1956 | April | 17, 1957 |
| December | 19, 1956 | May | 15, 1957 |
| January | 16, 1957 | | |

In addition to the regular program, the Chapter will sponsor a series of five seminars on mathematical and statistical tech-

niques at four to six-week intervals. The major topics covered will be work sampling and linear programming. The sessions will feature a review of fundamentals and illustrations of case examples which stress the application of the above techniques in solving problems of an industrial engineering nature. Each subject will be presented by qualified speakers. The seminars are designed to fill the needs of both our Chapter members as well as industrial representatives from this area.

Membership in the Chapter now stands at 111. This represents an increase of thirty per cent in the number of members over last year. We are continuing our efforts to get additional qualified individuals to join the Chapter.

The following officers have been elected for the 1956–57 season:

President—Michael Damroth, Merck Sharp & Dohme, Division of Merck & Co., Inc.

Vice President—George W. Hoffmeister, Brown Instrument Division, Minneapolis Honeywell Regulator Co.

Secretary—Frederick A. Cline, Jr., Leeds and Northrup Company

Treasurer—Merritt J. Sterling, Atlantic Refining Company.

**ST. LOUIS CHAPTER**

All meetings of the St. Louis Chapter this season will be held at Ruggeri's Restaurant, 2300 Edwards, on the second Wednesday of the month. The Program Committee has done an excellent job of lining up an interesting array of speakers, subjects and activities for the year.

The first meeting of the year was held on September 12. Dr. Nathan Kohn, Jr., Co-director of Nicholson-Kohn & Assoc., Inc., and nationally known Personnel Consultant, spoke on "Communications—Science or Art". Since leaving Washington University in 1938 with an A.B. and L.L.D., Dr. Kohn has led a full professional career. In 1942 he received his M.A. at the University of Minnesota and returned to Washington University for his Ed.P. in 1948. His path has led him through the fields of research in sociology, covering speed reading, interest measurement, industrial group dynamics, social group dynamics, psychology of learning, counseling, attitude measurement, mass motivation, areas of psychology, industrial relations, mental hygiene. He has served as the Chairman of the Ethical Practices Committee of the National Vocational Guidance Association, and published with the aid of a committee a directory of listings.

**TRI-CITIES TENNESSEE CHAPTER**

Members and their wives were treated to a delicious meal and an entertaining agenda at the Tri-Cities Tennessee Chapter's annual "Ladies' Night" dinner. The meeting was held May 23 at the Kingsport Inn.

The Chapter was honored in having Mr. Howard P. Emerson as its special guest. This was Mr. Emerson's first chapter visit following his election to the office of National President of A.I.I.E.

Mr. W. E. Seay, Paints Manager of the Knoxville office of the Pittsburgh Plate Glass Company, presented a program of interest to both the men and the ladies. His subject, "Color Dynamics in Industry and in the Home," was illustrated by means of a slide projector and was well received by the group.

A social hour, highlighted by dance music and refreshments, concluded a most enjoyable "Ladies' Night."

**TULSA CHAPTER**

The Tulsa Chapter of AIIE had at its September meeting Mr. Paul L. Smith, Chief of Operations Analysis, Douglas Aircraft, Tulsa, as its principal speaker. His subject was, "The Biggest Inch." In his talk Mr. Smith reviewed the part that air transport is playing in carrying cargo for the logistics pipeline of the Military. His presentation covered development of the present concept of logistics which includes cargo aircraft to a greater extent than ever before. This led to a discussion of a development of the "family" of cargo ships. It was interesting to note that the speed of flow of material from plant to front during World War II was only a fraction of a mile faster on the average than it was for General Washington.

Mr. Smith graduated from California Institute of Technology and has spent 17 years with the Douglas Aircraft Company. His present duties include market research.

**WICHITA CHAPTER**

A new Chapter of the A.I.I.E. was organized at Wichita, Kansas, during the fall of 1955. At the time of organization, there were only eight persons employed in Wichita that were members of the A.I.I.E.

Since the Chapter has been organized, considerable interest has developed; and as a result, the Chapter now has 24 members, and the attendance at the meetings has been twice this figure.

The present slate of officers that were elected in May to serve one year are:

S. D. Miner, President; Henry Bogardus, Vice-President; William Cochran, Secretary; Orville Paige, Treasurer; with David Totten, Gus Daum, and Harold Taylor to serve on the Board of Directors.

The Wichita Chapter meets the first Tuesday of each month September through May.

Recent programs have included discussions of Operations Research, Linear Programming, with the highlight being a talk in May by Gerald Nadler, Professor and Head of Department of Industrial Engineering, Washington University, and at that time, Vice-President, Midwest Region, A.I.I.E.

There are some very interesting and informative programs planned for the future. For the September meeting, the Chapter will be privileged to hear a talk and see a film presented by William Holly, Directing Representative, District 70, I.A.M., A.F.L. The subject and film will be on the controversial subject of "Right to Work".

In October, Dr. Irwin Lazarus, Vice-President of the Midwest Region, A.I.I.E., will be the guest speaker; and Kenneth Razak, Dean and Head of School of Engineering, University of Wichita, will be the guest speaker in December.

Some of the planned projects for the Chapter include helping organize a Student Chapter at the University of Wichita, and offering the services of the Chapter to certain public institutions in Wichita.

**GERMAN ENGINEERING CENTENNIAL**

One of the world's oldest engineering societies, the Verein Deutscher Ingenieure, celebrated its 100th anniversary in West Berlin last May. Over two thousand engineers from East as well as West Germany and most all parts of the world attended. The AIIE joined the world's other leading engineering societies in sending special greetings to the VDI, via President Slagle.

The program was fitting for the occasion, with such topics as machines and civilization, the place of the engineer, automation and others, general and special. Dr. Lillian Gilbreth was one of two foreigners honored by the special "Honor Ring" award of the Society, as were three Germans.

Professor E. C. Keachie represented AIIE at the meetings. He was on leave from Berkeley as Fulbright Professor at the Technische Hochschule, Darmstadt. The Rector of this well-known engineering college, Professor Dr. Kurt Kloeppel, was one of the three outstanding German engineers to receive a special award for his professional work.

**3rd National Symposium on Reliability and Quality Control in Electronics**

The 3rd National Symposium on Reliability and Quality Control in Electronics will be held at the Hotel Statler, Washington, D. C., in January. There will be two concurrent Sessions each of eight periods during a three day period, January 14, 15 and 16, 1957, which will include papers, panels, movies, plant tours and a banquet.

# RECENT READABLES

## AUTOMATION

The August 6, 1956 issue of *The Oil and Gas Journal* has a special section devoted to "Computers in Refining". The three articles comprising this section are as follows:

1. "Computers Optimize Gas-Plant Operations" by E. V. Merrick. An I.B.M. 650 electronic computer has been used to optimize operation of a Sohio catalytic-reformer gas plant. A 61-hour study on the machine enabled the determination of the effects of all the process variables and pointed the way to changed operating conditions and increased product value.
2. "Digital Computers Speed Gas Analysis" by H. A. Young. The time required for calculating the results of a mass spectrometer gas analysis can be shortened from an hour or more to 10 minutes by substituting a digital computer for a desk calculator.
3. "Computers Aid Gasoline-Blending Operations" by K. E. Frye & K. L. Shull. Conventional and special-type computers are being used by Sohio's manufacturing department to save money and manpower, and increase efficiency, accuracy and speed in gasoline-blending operations.

"Analog-To-Digital Conversion", by M. L. Klein, F. K. Williams and H. C. Morgan, *Instruments and Automation*, Pg. 911, May 1956.

This thorough discussion of digital conversion presents the three basic techniques—time, voltage, feedback, and space encoding. The principles and operation of each are presented, complete with discussion of relative features.

## GENERAL

"Present Status of the Work of Managing", by H. F. Smiddy, *Management Science*, April 1956.

Observations on the "science of management". The author discusses the purpose of, and need for, scientific management, appraises the present status of three important aspects of managerial work (objectives, organization and manpower planning), and suggests a 10-point outline of the principles on which scientific management is based.

"The Manager's Span of Control", by L. F. Urwick, *Harvard Business Review*, May–June, 1956.

A re-examination of the "span of control" concept, which holds that no superior can supervise directly the work of more than five or, at the most, six subordinates whose work interlocks. The author analyzes criticisms of this principle and attempts to demonstrate why and how a restricted span of control can improve executive effectiveness, reduce inefficiency, and foster cooperation, morale, and a sense of unity within the organizations.

"What Maintenance Plan for Handling Equipment?", by E. G. Fremont, *Flow*, May 1956.

Careful selection on the basis of design can eliminate many problems in the maintenance of material handling equipment, the author points out. Among other possible improvements, he suggests establishing a separate section for servicing and scheduling trucks, forklifts, autocranes, etc., as part of a combined "area-centralized" program.

"Improving Staff and Line Relationships", *Conference Board Reports*, Studies in Personnel Policy, No. 153.

This report is a study and analysis of the staff and line relationship as it currently exists in business and industry in the United States. The data on which this study is based were secured by personal interview with over 300 executives in seventy-eight different companies. Organization manuals, charts and material illustrative of staff procedures in some 200 additional companies were also studied.

"Making A Permanent Place for Cost Reduction", by R. P. Neuschel, *The Management Review*, Pg. 534, July 1956.

The line supervisor is the key man in any cost reduction program. Cost reduction, however, is a team job. Individual supervisors can no longer be expected to cope single-handed with all the problems posed by today's highly mechanized operations, in addition to discharging their growing responsibility for the welfare of their personnel.

The kind of administration that will usually produce the best results may be summarized in the five-point list below:

1. Over-all authority and leadership should be vested in a member of the line organization.
2. Staff men should assist the leader by developing ideas independently of, and in conjunction with, members of line supervision.
3. Each line supervisor should participate in analyzing his department's activities and in setting cost-saving objectives.
4. The line supervisor will spearhead the introduction of any changes in his own department.
5. Staff men's main responsibilities will be to generate ideas and act as coordinators in bringing the whole program together.

## INVENTORY CONTROL

"Some Models of Inventory and An Application", by E. Naddor, *Management Science*, Pg. 299, July 1956.

This paper is concerned with two topics: (1) the development of mathematical models for several simple inventory situations, and (2) an industrial application of a mathematical model of inventory. This paper is not an attempt to solve the "general inventory problem". Rather, the object is to deal with specific situations, and with an illustrative industrial application. The emphasis is on methodology of approach rather than on a general solution.

## MATERIALS HANDLING

"Systematized Approach Pays Handling Profits", *Iron Age*, Pg. 105, June 14, 1956.

Integrated handling is the theme of today's material handling strategist—systematization in tackling plant problems, rather than the old sniper approach. Automation demands it. And automated or not, the trend is definitely in that direction. Here's what some of the country's front-running experts had to say at the technical sessions staged with the Cleveland Handling Show held in June.

"Schedule Your Shipping Workload", by N. Drake, *Modern Materials Handling*, Pg. 137, September 1956.

Planning and scheduling have become so much a part of manufacturing that it would be inconceivable to attempt to run a business without them. Yet materials handling in ship-

ping and receiving operations usually is carried on without the benefits of workload scheduling.

Most receiving is done in the morning, shipping in the afternoon. Accordingly, most plants experience a great deal of congestion at the receiving dock in the morning, with a corresponding rush and confusion in the afternoon in the shipping department.

The problem was analyzed in detail in a study recently completed for the Transportation Committee on Practices and Procedures of the National Traffic Committee and two Conferences of The American Trucking Associations, Inc. This analysis resulted in a plan for setting up and operating a scheduling procedure which would serve in almost any receiving and shipping department.

"How to Use Dragline Conveyors", by H. J. McCormick, *Modern Materials Handling*, Pg. 120, September 1956.

Few of the many types of materials handling equipment available today have captured the imagination of engineers and designers as has the dragline installation. This interest probably stems from three major characteristics of these systems: their practicability in the solution of many problems, their inherent flexibility in two planes, and their built-in ability to serve many stations. With these features, together with moderate cost and long service life, few basic misapplications of dragline systems are possible.

"Hopper Feeders: Best Bet for Small Plant Automation", by W. G. Patton, *Iron Age*, Pg. 95, August 23, 1956.

Relatively simple, low-cost devices called hopper feeders take the monotony out of many jobs. They'll feed small parts of a great variety of shapes and sizes to machines at speeds far in excess of the most deft hands. They do it without getting tired and with far fewer mistakes. Moreover, they'll perform their jobs with a degree of safety that every plant would like to match.

To small firms making products involving many small parts, hopper feeders bridge the gap between hand-fed operations and fully automatic production. To others, it may mean the difference between staying in business and going out of it under competitive pressures. One plant manager who knows puts it this way: "Hopper feeders are the poor man's best bet in the hectic race toward automatic manufacturing".

"Materials Handling Factors to Remember in a New Plant", by G. P. Brown, *Plant Administration*, June 1956.

Inadequate attention to details in the planning stage of new-plant construction often results in a factory's failing to operate at full effectiveness. This article outlines 10 important considerations relating to materials handling that should be evaluated while the new plant is being designed, when it is still relatively easy to correct errors.

"101 Money-Saving Ideas", *Flow*, June 1956.

A compilation of materials-handling techniques and devices that various companies have found practical in their operations. The ideas are classified under nine headings: manufacturing, processing, assembly, in-plant storage, warehousing, yard handling, packaging, shipping and dock handling.

"Your Responsibility for Company Profits", by J. T. Garrity, *Flow*, May 1956.

Materials handling executives should proceed cautiously in the installation of new equipment or improved warehousing, even though the change may appear profitable on the surface, the author states. All such projects should be based solely in terms of over-all improvement in the company's profit position. This article is intended as a guide to evaluating the elements involved.

"Better Packaging Stems from Simple Ideas", by H. H. Lamar, *Iron Age*, Pg. 102, August 23, 1956.

Packaging is admittedly a necessary function in making and shipping a product. But too often—since the customer eventually pays the cost—packaging is dismissed without any great attention to how its cost might be reduced.

Today, too many plants schooled in this kind of thinking are losing ground to their more alert competitors; those who see in packaging attractive opportunities for saving time, money, labor and materials.

North American Aviation has taken some simple but highly effective swipes at cutting packaging costs . . . These three ideas alone—spring steel fasteners, modular packaging, tape suspension—saved thousands . . . All are broadly adaptable.

## OPERATIONS RESEARCH

"Operations Engineering", by E. R. Bowerman and S. B. Littauer, *Management Science*, Pg. 287, July 1956.

Interest in management science, especially under the name "operations research", on the part of industry has grown since World War II. The techniques have become more fully developed and the purpose of this article is to develop some conclusions drawn from experience in applying the concepts. These conclusions resulted from an analysis of what was needed to apply operations research techniques to manufacturing. In particular, attention was given to stabilizing procedures, to making decisions in the face of uncertainty and to improving communication. It was found that these and related operating problems could be handled in an engineering fashion so that operations research would be more effective.

"A Fruitful Application of Static Marginal Analysis", by H. W. Karr and M. A. Geisler, *Management Science*, Pg. 313, July 1956.

This paper describes the application of the technique of simple "marginal analysis" to an Air Force problem and suggests that a similar application may be useful in many industrial situations. Examples of such industrial problems are also presented.

"Geographical Distribution of Production in Multiple Plant Operations", by J. D. Dillon, *Management Science*, Pg. 353, July 1956.

The primary purpose of the report is to point up the interrelations found among selected conflicting company objectives, the criteria by which one may evaluate alternate course of action indicated by each of the stated objectives, and some methods for reducing similar problems to a reasonable size, susceptible of analysis by available mathematical techniques.

By taking into account only the "important" producing plants, products, consumers, one transportation network, and the existence of discrete levels of production, it is possible to reduce this non-linear programming problem to a finite set of linear programming problems, which can be handled on a digital computer. However, by application of suitable criteria, it is further possible to reduce the set of linear programming problems to their simplest form, the "transportation" problem, and to eliminate from further analysis a large number of the members of the set, and finally to reduce the "transportation" problems remaining to modest dimensions such that all the computations necessary may be done within a few hours on a desk calculator.

## QUALITY CONTROL

"A Check Inspection and Demerit Rating Plan", by H. F. Dodge and M. N. Torrey, *Industrial Quality Control*, Pg. 5, July 1956.

This plan was developed for use under circumstances where the customer has prior knowledge that the manufacturer's processes are normally well controlled and that the product has undergone adequate prior inspections before being sub-

mitted to the inspection agency. Contributory information on these matters is obtained through quality surveys, which are an important part of the over-all quality assurance plan. Another important part of the over-all plan is the analysis of complaint information which serves as an added check on the specification, production and inspection processes.

## SYSTEMS AND PROCEDURES

"A Mathematical Model for Integrated Business Systems", by I. J. Lieberman, *Management Science*, Pg. 327, July 1956.

This paper presents a mathematical technique for investigating integrated business systems based on the mathematical notion of matrices. The assumption is that the information requirements of the various business functions are known. The problem involves finding an optimal data processing system for such requirements, given a series of "report levels".

This type of problem solving is important because of the opportunity which is offered the analyst to incorporate in his system the advances which are taking place in programming, scheduling and feedback—both conceptually and in terms of electronic equipment.

"Continuous Flow", by F. D. Fernsler, *Modern Office Procedures*, June 1956.

Executives concerned over bottlenecks in the order-processing system may be interested in how one medium-sized manufacturer has solved the problem. Adopting the idea of continuous work flow from its own factory methods, the company installed a conveyor belt to carry all incoming orders through the various processing stations directly to shipping.

"Automation Research at Minneapolis-Honeywell", by A. M. Wilson, *The Office*, May 1956.

The management philosophy underlying this company's current planning in office automation is stated here by its executive vice president. He examines the content and purpose of Minneapolis-Honeywell's present feasibility studies, as well as the likely impact of automation and electronic data-processing on the company's long-range goals—particularly in the area of managerial decision-making.

"Elements of Office Automation—and Preparing For It", by H. C. Heiser, N.A.C.A., *Bulletin*, June 1956.

Thoroughgoing systems analysis and program design are basic to the successful installation of computers and data-processing equipment, the author emphasizes. He defines the types of data that lend themselves to automatic processing, compares the performance of manual and mechanical systems with that of the electronic devices which can replace them, and outlines the steps that should precede installation.

"4,000 Items—4 Buyers", by D. S. Ammer, *Purchasing*, March 1956.

A description of purchasing operations at the DeLaval Separator Company, where cost reductions have been effected and work efficiency promoted by a program of paperwork simplification, expediting and follow-up, integrated record-keeping, and departmental meetings. A traveling requisition form, complete with the required specifications and previous purchase history, is one of the tools described.

## WORK MEASUREMENT

"Internal Relations of Elemental Motions Within a Task", by N. B. Hall, Jr., *The Journal of Applied Psychology*, Pg. 91, April 1956.

Time-and-motion economy often has as its foundation an atomistic concept of human behavior. Revision and improvement of work cycles are made on the assumption that the individual elements which make up the total complex task can be removed or rearranged as though these elements are independent units. The elimination of a designated undesirable element is assumed to benefit the total time to perform the task.

The purpose of the auther's study was to provide further evidence concerning the extent of interaction of elements in an actual factory operation, thereby suggesting additional information upon which to reject the atomistic concept of human behavior in connection with micro-motion analysis.

## BOOKS

*How to Calculate Quickly*, by Henry Sticker. Dover Publications, 920 Broadway, New York 10, New York, 264 pages, $1.

Many engineers require slide rules to perform calculations which a billing clerk would do mentally, states Mr. Sticker. This pocket-size book contains nearly 400 short, graded exercises for the development of a number sense which will increase proficiency in mathematics. This publisher offers several inexpensive books on interesting and useful mathematical subjects, a list of which can be had from above address.

*Worker Satisfaction and Development*, by A. Zaleznik. Harvard Business School, Soldiers Field, Boston 63, Massachusetts, 148 pages, $2.

This paper-bound volume, subtitled "A Case Study of Work and Social Behavior in a Factory Group", explores the life on the job of fourteen men in a small machine shop.

One value of the book lies in the fact that the material was not gathered to support any preconceived hypothesis. In fact, a very small part of the book is devoted to generalization.

*Techniques of Plant Maintenance and Engineering*, published by Plant Maintenance Show, Inc. (Clapp & Poliak, Inc.) 1956, New York 17, New York, 248 pages. Price $10.

This is a compilation of the technical sessions held concurrently with the Seventh National Plant Maintenance and Engineering Show in Philadelphia, January, 1956. Of especial interest to maintenance managers, it covers the field of plant housekeeping thoroughly, including preventive maintenance, sanitation, equipment replacement policies, using outside contractors, and maintenance during 24-hour production schedules. There are some interesting discussions of teamwork and cooperation and how to achieve them; problems peculiar to specific types of plants; report writing, and various tricks of the trade.

*Management in Action*, by L. A. Appley, published by American Management Association, 1956, New York 36, New York, 382 pages. Price $5.

As a treatise on "the art of getting things done through people", this book is more nearly a work on philosophy than a technical guide. It discusses problems of human nature and methods of solution; delves into attitudes and motivations, and illustrates with anonymous case histories and anecdotes.

Among the topics that come under Mr. Appley's able and penetrating scrutiny are the structure and nature of a company; discipline and decency; management craftsmanship; time and how to spend it; communications; tools and techniques of management; personnel administration, and professional management's meaning and future.

*Automation and Electronics; A Guide to Company Experience*, Management Research Service, 1342 Cherry Street, Kalamazoo, Michigan, $1.00.

This booklet pulls together in a handy reference volume much valuable material not available in any other one source. It covers more than 200 outstanding case studies contained in books, conference proceedings and important periodicals in the fields of automation, electronics, and general management. Seventy percent of these case studies are not listed in the standard indexing services. This booklet is organized, (1) according to important aspects of the subject of automation, and (2) according to major industry. An alphabetical index of companies has been included to facilitate the location of references to particular companies.

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